Consumer Durables and Monetary Transmission in a Two-sector HANK Economy*

Emil Holst Partsch†
DREAM

Ivan Petrella‡
University of Warwick & CEPR

Emiliano Santoro§
University of Copenhagen

March 1, 2023

Abstract

We quantify the direct (interest-rate) and indirect (general-equilibrium) effects of monetary policy transmission in a two-sector Heterogeneous Agent New Keynesian (HANK) setting with both durable and nondurable consumption goods. Indirect effects are further decomposed into the response of either good's consumption that can be ascribed to relative-price changes and "pure" income effects. Given a realistic share of liquidity-constrained households, pure income effects represent the most significant transmission channel of monetary shocks, and are key in generating positive comovement between durable and nondurable expenditure. Moreover, we document substantial direct effects of monetary shocks on aggregate consumption—relative to standard one-sector HANK models—due the marked interest-rate sensitivity of the durable-consumption component.

Keywords: Heterogeneous agents, durable goods, multi-sector models, monetary policy.

JEL codes: E21, E31, E40, E44, E52.

*We wish to thank Davide Debortoli, Jeppe Druedahl, Francesco Saverio Gaudio, Erik Öberg, Søren Hove Ravn, and Petr Sedlacek for useful comments.

†DREAM, Danish Research Institute for Economic Analysis and Modelling, Landgreven 4, Copenhagen K, DK-1301 Denmark. E-mail: emipar@dreamgruppen.dk.

‡Warwick Business School, University of Warwick, Scarman Building, Gibbet Hill Road, Coventry, CV4 7AL, UK. Email: ivan.petrella@wbs.ac.uk.

§Department of Economics, University of Copenhagen, Øster Farimagsgade 5, Copenhagen K, DK-1353, Denmark. Email: emiliano.santoro@econ.ku.dk.

1 Introduction

A flourishing literature has emerged with the aim of incorporating rich household heterogeneity into the workhorse New Keynesian model, yielding learnings that profoundly change our understanding of the transmission of monetary policy. A main insight of these economies is that, in the presence of transitory income shocks, general-equilibrium effects drive the brunt of the response to monetary policy shocks (Kaplan et al., 2018; Auclert, 2019). This stands in stark contrast with the predictions of Representative Agent New Keynesian (RANK) economies, where nearly the entire response is driven by intertemporal substitution. Such Heterogeneous Agent New Keynesian (HANK) models typically feature one sector that produces one type of (perishable) consumption good. However, it is well known that durable spending is much more interest-rate sensitive than nondurable spending (see, e.g., Mankiw, 1985), along with typically being more volatile over the business cycle. Since durables differ in important ways from nondurables, being both a consumption good and a store of value involved in household-portfolio choices, it seems legitimate to ask whether the lessons learned from one-sector HANK frameworks carry over to richer models of consumption. More specifically: what are the main propagation channels of monetary shocks on durable and nondurable expenditure in the presence of meaningful wealth heterogeneity? And, further, how does the answer to such question help us refine our understanding of monetary policy transmission?

To address these questions, we devise and calibrate a two-sector HANK model based on US data. We retain the building blocks of standard two-sector New Keynesian models with asymmetric price stickiness between sectors, in the vein of Barsky et al. (2007) and Monacelli (2009), augmented to reflect uninsurable idiosyncratic risk on the household side.[1] We then decompose the response of consumption on both durables and nondurables to a contractionary monetary policy shock into a *direct* (or interest-rate) effect—as dictated by intertemporal substitution—and an *indirect* effect, which operates through the general-equilibrium increase in households' disposable income. In turn, the latter is further decomposed into the response that can be reconducted to changes in the *relative price* of durables to nondurables—which incorporate both income and substitution effects—and *pure income* effects.

[1]Relative to the HA literature that deals with durable expenditure at the household level, we focus on durable adjustment along the intensive margin, rather than on the extensive margin (in this respect, see Berger and Vavra, 2015, Harmenberg and Öberg, 2021, McKay and Wieland, 2021, among others).

We show that interest-rate effects account for a non-negligible fraction of the total response of consumer durables, even though the brunt of the response of both durables and nondurables is represented by pure income effects, in line with the quantitative insights from one-sector HANK economies à la Kaplan et al. (2018). When it comes to decomposing the reaction of aggregate consumption, though, direct and indirect (i.e., pure income + relative-price) effects have an almost equal share into the total response, thus indicating that—through durables—monetary transmission via intertemporal substitution still has substantial grip, relative to one-sector HANK models with nondurables only.

We also show that pure income effects are key in overcoming the relative-price force that induces consumers to substitute durables for nondurables and *vice-versa*—depending on the relative degree of sectoral price stickiness—so as to address the comovement puzzle that typically plagues otherwise standard two-sector RANK models with asymmetric sectoral price stickiness (see, e.g., Barsky et al., 2007). In this respect, decomposing household-level consumption based on liquid-wealth holdings highlights some distinctive traits of different household types. As for the savers, the sharp reallocation of resources between their stock of durables and bond holdings in the face of a monetary shock reflects sizable capacity of the interest-rate channel for these agents, though the inherent weakness of pure income effects ultimately determines negative comovement between their consumption of durables and nondurables. As for financially-constrained households, instead, their consumption of each type of good display positive conditional comovement, thus making these agents' cosumption habits and share into the total population decisive for resolving the comovement puzzle.

These results are robust to realistic extensions to the baseline framework, such as deficit financing. We also augment the model to feature sticky wages (see, e.g., Auclert et al., 2020b). In this case, pure income effects are responsible for an even larger share of the response of both types of consumption, being relative-price effects more muted. While interest-rate changes appear as less of a driver of the response of durables, as compared with the case of flexible wages, it is still the case that durables are more interest-rate sensitive than nondurables, ultimately implying sizable direct effects of monetary policy on aggregate consumption.

All in all, our results are important in that they should lead to rethink the most effective channels of transmission of monetary policy in HA economies, when focusing on both aggregate consumption and its components characterized by different degrees of durability.

Related literature We relate to a burgeoning literature on monetary policy transmission in New Keynesian models with rich wealth distributions. Our work is inspired by the seminal work of Kaplan et al. (2018), who investigate the effects of monetary policy in a rich calibrated one-sector HANK model. In this respect, we also relate to Alves et al. (2020), who expand on the same one-sector framework, emphasizing the role of fiscal adjustments outside the steady state. Another relevant contribution is Auclert (2019), who report that redistribution triggered by monetary policy is key in amplifying its effect in the aggregate. Relative to these papers, we extend the analysis to a two-sector HANK setting, and show how (indirect) pure income effects dominate the response of both durables and nondurables, with the former still being more interest-rate sensitive than the latter. In this respect, we also relate to McKay and Wieland (2022), who build a model that features durable adjustment along the extensive margin, exploiting its sensitivity to the (contemporaneous) user cost to address the forward guidance puzzle. We abstract from this channel, while casting an otherwise standard two-sector NK model in a HA setting, so as to retain closer comparability with the long-standing tradition that studies monetary transmission in multi-sector economies.

Our paper also relates to a large literature tackling the *comovement puzzle* that typically characterizes standard two-sector New Keynesian models with asymmetric price rigidity. Remedies that have been put forward to address this puzzle can essentially be divided into three categories: *i*) opting for non-separable preferences between a composite of sectoral consumption goods and labor supply (see, e.g., Dey and Tsai, 2012; Katayama and Kim, 2013); *ii*) adopting sticky prices of the production inputs, such as Carlstrom and Fuerst (2010)—who assume sticky wages—or Sudo (2012) and Petrella et al. (2019), who both allow for input-output interactions; *iii*) embedding financial frictions in the vein of Tsai (2016)—who stresses the role of working capital—or Monacelli (2009), who emphasizes the importance of the collateral constraints applying to households. All of these modeling devices influence the extent of the fall in the relative price of durables (the latter are typically assumed to display prices that are more flexible than those of nondurables), in the face of a monetary tightening. Our framework takes a different route, and reproduces sectoral comovement not by weakening the relative-price channel, but by highlighting the importance of transitory income movements in the presence of market incompleteness.

Structure The paper is structured as follows: Section 2 details the baseline two-sector HANK model. Section 3 details the calibration and the solution of the deterministic steady state. In Section 4 we generate the responses to a monetary policy shock and decompose them into direct, relative-price, and pure income effects. In Sections 4.3 and 4.4 we extend the baseline model to account for deficit financing and sticky wages, respectively. Section 5 concludes.

2 A two-sector HANK model with durables

The economy is populated by households with preferences over durable and nondurable consumption, as well as labor hours that are supplied to intermediate-goods firms operating in a regime of monopolistic competition. The latter, in turn, sell their products to firms operating in a perfectly-competitive final-goods sector. The government pursues monetary policy, while balancing its budget on a period-by-period basis. The remainder of this section details the key blocks of the model, as well as how equilibrium obtains.

2.1 Households

We assume a continuum of households, indexed by $s \in [0, 1]$. Consumer preferences are defined over (a Cobb-Douglas aggregator of) nondurable consumption and the stock of durables—$C_{n,t}(s)$ and $D_t(s)$, respectively—[2] as well as over labor hours, $\mathcal{N}_t(s)$. Households' intertemporal utility reads as

[2]Concerning the transmission of monetary impulses through movements in the relative price, the assumption of Cobb-Douglas preferences is rather conservative, as the empirical estimates of the substitution elasticities between durables and nondurables range from below one to around one; see Ogaki and Reinhart (1998), Davis and Ortalo-Magné (2011), Pakos (2011) and Albouy et al. (2016). We stand at the higher end of these estimates.

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_{n,t}^{\theta}(s) D_t^{1-\theta}(s)\right)^{1-\sigma}}{1-\sigma} - \psi_N \frac{\mathcal{N}_t^{1+\varphi}(s)}{1+\varphi} \right] \right\}. \tag{1}$$

We define the durable flow as $C_{d,t}(s) = D_{t+1}(s) - (1-\delta)D_t(s)$. Household s's budget constraint (deflated by the price of nondurables) is given by

$$\begin{gathered} C_{n,t}(s) + Q_t C_{d,t}(s) + B_{t+1}(s) = \\ \left(1 + r(B_t(s))_t\right) B_t(s) + w_{n,t} N_t \exp\{e_t(s)\} + Div_t \overline{Div}(s) - \tau_t \bar{\tau}(s) - \frac{\alpha}{2} \left(\frac{C_{d,t}(s)}{D_t(s)}\right)^2 D_t(s), \end{gathered} \tag{2}$$

where $B_{t+1}(s)$ denotes bond holdings, Q_t is the price of durables relative to that of nondurables, $w_{n,t}$ is the real wage rate,[3] α scales the adjustment cost on durables, $\delta \in [0,1]$ is the depreciation rate and $e_t(s)$ is an idiosyncratic productivity shock with unit mean. Furthermore, $r(B_t(s))_t$ is the real return on bonds when $B_t(s) > 0$, while it equals the real rate plus a borrowing wedge, κ, when $B_t(s) < 0$ (see Kaplan et al., 2018). Households pay taxes, τ_t, and receive dividends, Div_t, from the ownership of firms, according to the incidence rules $\bar{\tau}(s)$ and $\overline{Div}(s)$, which are set so that taxes and dividends are linear functions of individual productivity. Finally, households face a borrowing constraint:

$$B_t(s) \geqslant -\psi Y, \tag{3}$$

where Y is steady-state total output, and ψ is a scaling parameter. We assume that all households supply labor according to the solution given by the RA representation of the model (see, e.g., Debortoli and Galí, 2021), that is:

$$w_{n,t} = \psi_N N_t^{\varphi} \frac{1}{\theta} \left(C_{n,t}^{\theta} D_t^{1-\theta}\right)^{\sigma} \left(\frac{C_{n,t}}{D_t}\right)^{1-\theta}, \tag{4}$$

where $C_{n,t} \equiv \int_0^1 C_{n,t}(s) ds$

and $N_t = \mathcal{N}_t(s)$ for all s.[4]

[3] Formally, this is indexed by "n", as we deflate the nominal wage by the price level of nondurables. However, it is important to recall that, as we assume perfect labor mobility, nominal wages are equalized across sectors.

[4] Taking a representative-agent stand on labor supply allows us to dampen wealth effects for low liquidity households, which helps reconcile the model with the available evidence (see, e.g., Auclert et al.,

2.2 Production

Final-goods producers There are two sectors, indexed by $j = \{n, d\}$. Two representative sectoral final-goods producers aggregate a continuum of intermediate goods indexed by $i \in [0, 1]$, $y_{j,t}(i)$ (with price $p_{j,t}(i)$), in accordance with a CES technology:

$$Y_{j,t} = \left(\int_0^1 y(i)_{jt}^{\frac{\epsilon_j - 1}{\epsilon_j}} di \right)^{\frac{\epsilon_j}{\epsilon_j - 1}}, \tag{5}$$

where ϵ_j is the elasticity of substitution across goods of type j. Given $Y_{j,t}$, profit maximization for the jth final goods producer implies a demand for intermediate good i in the same sector:

$$y(i)_{j,t} = y\left(p(i)_{j,t}; P_{j,t}, Y_{j,t}\right) = \left(\frac{p(i)_{j,t}}{P_{j,t}} \right)^{-\epsilon} Y_{j,t}, \tag{6}$$

where $P_{j,t}$ denotes the equilibrium price of the final good:

$$P_{j,t} = \left(\int_0^1 p(i)_{jt}^{1-\epsilon_j} di \right)^{\frac{1}{1-\epsilon_j}}. \tag{7}$$

Intermediate-goods producers Intermediate-goods producers in either sector employ a linear production technology:

$$Y_{j,t}(i) = A_j N_{j,t}(i), \tag{8}$$

where A_j represents total factor productivity, assumed to be common to all firms in sector j. Price setting in each sector is subject to virtual Rotemberg adjustment costs $\mathcal{C}_j(\cdot) = \frac{\xi_j}{2} \left(\frac{P_{j,t}(i)}{P_{j,t-1}(i)} - 1 \right)^2 Y_{j,t}$ (with $\xi_j > 0$) as in, e.g., Hagedorn et al. (2019). Each firm's value function in real terms reads as

2020a).

$$V_{j,t}^{IGF}\left(p(i)_{j,t-1}\right) \equiv \max_{p(i)_{j,t}} \frac{p(i)_{j,t}}{P_{j,t}} y\left(p(i)_{j,t}; P_{j,t}, Y_{j,t}\right) - w_{j,t} N_{j,t} - \frac{\xi_j}{2}\left(\frac{p(i)_{j,t}}{p(i)_{j,t-1}} - 1\right)^2 Y_{j,t} + \beta V_{j,t+1}^{IGF}\left(p(i)_{j,t}\right). \tag{9}$$

This problem yields the usual New Keynesian Phillips curve(s):

$$(1-\epsilon_j) + \epsilon_j w_{j,t}/A_j - \xi_j\left(\Pi_{j,t}-1\right)\Pi_{j,t} + \beta\xi_j\left(\Pi_{j,t+1}-1\right)\Pi_{j,t+1}\frac{Y_{j,t+1}}{Y_{j,t}} = 0, \tag{10}$$

while total real dividends (deflated by $P_{n,t}$) are

$$Div_t = \sum_j Div_{j,t} = Y_{n,t} - w_{n,t}N_{n,t} + Q_t\left(Y_{d,t} - w_{d,t}N_{d,t}\right). \tag{11}$$

2.3 Policy

Monetary policy Monetary policy sets the nominal rate according to a Taylor rule that features a shock, u_t^r:

$$i_t = \phi_{\tilde{\pi}}\tilde{\pi}_t + u_t^r, \tag{12}$$

where $\tilde{\pi}$ is the net (aggregate) rate of inflation, with $\tilde{\Pi}_t \equiv \Pi_{n,t}^{1-\gamma}\Pi_{d,t}^{\gamma}, \gamma \in [0,1]$.

Fiscal policy The fiscal authority issues one-period nominal bonds, B^g, maintaining this constant in fulfillment of the steady-state bond-to-output ratio, and adjusts the level of lump-sum taxes, τ_t, to balance its budget period-by-period:

$$\tau_t = r_t B^g. \tag{13}$$

2.4 Equilibrium

Market clearing Bonds market clearing obtains as

$$B_t = \int_0^1 B_t(s)ds = B_g. \tag{14}$$

Aggregate labor hours are given by

$$N_t = \sum_j \int_0^1 N_{j,t}(i)di = \sum_j Y_{j,t}/A_j, \tag{15}$$

and are assumed to be distributed uniformly among household types, i.e. $N_t(s) = N_t$ for all $s \in (0, 1)$. The sectoral resource constraints are

$$Y_{d,t} = C_{d,t}, \tag{16}$$

and

$$Y_{n,t} = C_{n,t} + \chi_t + \kappa \int \max(-B_t(s), 0)ds, \tag{17}$$

where the last two terms respectively capture the costs of adjusting the stock of durables and borrowing. It follows from equations (16) and (17) that the market for aggregate goods clears by

$$Y_t = Q_t Y_{d,t} + Y_{n,t} = Q_t C_{d,t} + C_{n,t} + \chi_t + \kappa \int \max(-B_t(s), 0)ds. \tag{18}$$

Equilibrium definition An equilibrium in this economy is defined as paths for individual household decisions, $\{C_{n,t}(s), D_t(s), B_t(s)\}_{t\geqslant 0}$, inflation rates and relative prices, $\{\Pi_{n,t}, \Pi_{d,t}, Q_t\}_{t\geqslant 0}$, real wages, $\{w_{n,t}, w_{d,t}\}_{t\geqslant 0}$, sectoral output and employment, $\{Y_{n,t}, Y_{d,t}, N_{n,t}, N_{d,t}\}_{t\geqslant 0}$, dividends, $\{Div_t\}_{t\geqslant 0}$, interest rates, $\{i_t, r_t\}_{t\geqslant 0}$, government bond supply and taxes, $\{B_t^g, \tau_t\}_{t\geqslant 0}$, such that:

1. Households maximize their objective functions, given the $\{Q_t, r_t, w_{n,t}, N_t, Div_t, \tau_t, \}_{t\geqslant 0}$

sequences;

2. Firms in each sector maximize their profits, taking as given the $\{w_{n,t}, w_{d,t}\}_{t\geqslant 0}$ sequences;

3. Given the $\{C_{n,t}, D_t\}_{t\geqslant 0}$ sequences, the real-wage sequences, $\{w_{n,t}\}_{t\geqslant 0}$ and $\{w_{d,t}\}_{t\geqslant 0}$, are consistent with the wage schedule, (4), conditional on perfect sectoral mobility, as captured by $Q_t w_{d,t} = w_{n,t}$;

4. The government budget constraint, (13), is satisfied;

5. Bonds, labor, nondurable and durable goods markets clear;

6. Distributions fulfill consistency requirements.

3 Calibration

An overview of our (quarterly) calibration is presented in Table 1. We calibrate the discount factor, β, so the steady-state annual real risk-free rate is 3 percent. The coefficient of relative risk aversion, σ, and the inverse Frisch elasticity of labor supply, φ, are set to 1. The utility weight on nondurables, θ, is set to 0.7 to match a steady-state nondurable to total consumption ratio of 0.60, which is in the middle of the range provided in Beraja and Wolf (2021). Durables' depreciation, δ, is set to 0.068, as in McKay and Wieland (2021). The idiosyncratic income parameters, σ_e and ρ_e, are set to 0.1928 and 0.9777, respectively, following McKay et al. (2016) and Auclert (2019). On the supply side, we set ϵ_n and ϵ_d to 0.6, as in Monacelli (2009). As for the policy parameters, the steady-state government debt-to-output ratio is set to 0.26, as in Kaplan et al. (2018). The reaction parameter in the Taylor rule, ϕ_π, is set to 1.5. The weight on durables in the monetary authority's inflation index, γ, is set to the steady-state share of durable consumption to total consumption. Finally, we implement the simulated method of moments (SMM), using α and ξ_n, ξ_d to target: *i*) the relative volatility of durable to nondurable consumption, calculated using log quantities of HP-filtered data; *ii*) the stickiness of durable and nondurable prices.[5] We target Calvo probabilities (i.e, the sectoral probabilities of not being able to adjust prices in a given quarter) of 0.75 and 0.25 for nondurable and durable prices, respectively, given

[5]The relative volatility of durables to nondurables is computed as the *on-impact* relative response to a 0.25% monetary policy shock with persistence set to 0.5, as in Kaplan et al. (2018).

that Nakamura and Steinsson (2008) report median price durations between 8 and 11 months (with one of the most prominent durables, *transportation goods*, denoting a price duration of 2.7 months; see their Table II). As there is no clear-cut sorting of durables and nondurables in the micro price-setting literature, we take these Calvo probabilities as being within plausible ranges. Thus, we impose durables to be more price-flexible than nondurables, as is standard in the business-cycle literature.[6]

We note that, based on this calibration, the unconditional correlation between durable and nondurable consumption amounts to 0.495 (conditional on our baseline monetary policy shock, and measured over 10 quarters), which is very close to the same moment computed with NIPA HP-filtered data (0.422).

Table 1: Baseline model calibration

Parameter	Value	Target/Source
Household parameters		
β	0.9652	Steady-state adjustment
σ	1	Std. business-cycle literature value
φ	1	Std. business-cycle literature value
θ	0.7	$\frac{C_n}{C_n+C_d}$; Beraja and Wolf (2021)
α	0.119	SMM target volatility of $C_d/C_n = 3.572$; BEA, NIPA accounts
δ	0.068	BEA Fixed Asset, McKay and Wieland (2021)
ψ_N	0.764	Steady-state adjustment
ψ	0.833	Average quarterly steady-state wage
κ	0.0465	Steady-state share of households with $B(s) = 0$; Kaplan et al. (2018)
ρ_e	0.9777	McKay et al. (2016) and Auclert (2019)
σ_e	0.1928	McKay et al. (2016) and Auclert (2019)
Supply-side paramaters		
r	0.03/4	Debortoli and Galí (2021)
ϵ_n, ϵ_d	6	Monacelli (2009)
ξ_n	20.21	SMM target Calvo probability of 0.75; Nakamura and Steinsson (2008)
ξ_d	5.43	SMM target Calvo probability of 0.25; Nakamura and Steinsson (2008)
A_n	1.0	Steady-state adjustment
A_d	2.16	Steady-state adjustment
Policy parameters		
B^g/Y	0.26	Liquid assets/GDP; Kaplan et al. (2018)
ϕ_π	1.5	Taylor (1993)
γ	0.40	Steady-state $C_d/(C_n + C_d)$

[6] We rely on the mapping between Calvo probabilities and Rotemberg adjustment costs, $\xi_j = \theta_j^{Calvo}(\epsilon_j - 1)/((1-\theta_j^{Calvo})(1-\beta\theta_j^{Calvo}))$, where θ_j^{Calvo} is the probability of not being able to adjust prices in sector j. From this, we obtain $\theta_n^{Calvo} = 0.62$ and $\theta_d^{Calvo} = 0.40$ (corresponding to median price durations of 7 and 5 months, respectively), and a relative on-impact volatility of C_d to C_n of 3.560. This value is in line with the available evidence in Erceg and Levin (2006) and Sterk and Tenreyro (2018), among others.

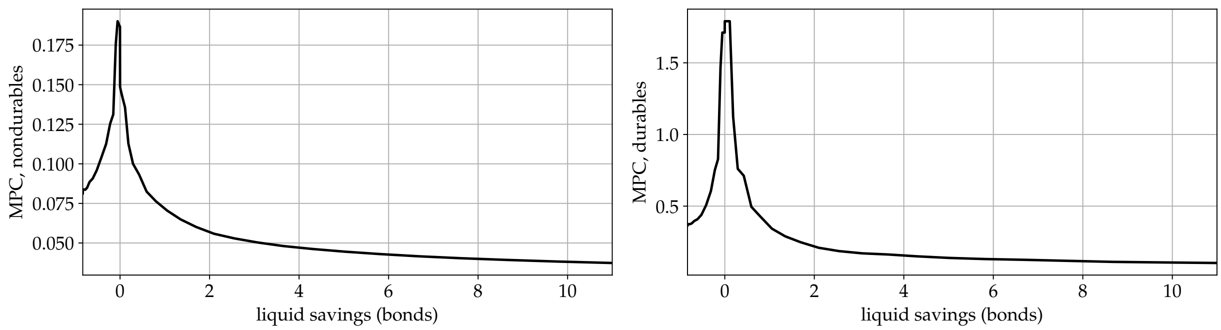
3.1 Deterministic steady state

Let a generic variable x_t be denoted by x in the steady state. When solving for the steady state, we use a multi-dimensional root finder to guess on β, Q, N_d, to target: *i*) bonds market clearing; *ii*) durable goods market clearing; *iii*) total employment ($N = 1$). Given bonds and durable goods markets clearing, the nondurable goods market clears by Walras' law. The household solution is obtained using the endogenous grid method algorithm of Auclert et al. (2021) in two dimensions; see Appendix A. The steady-state distribution is retrieved by relying on the deterministic histogram method of Young (2010). Given guesses for β, Q, N_d, we can solve for equilibrium quantities, as described in Appendix B.

We obtain a steady-state skewness of the durable stock over nondurable consumption of 0.867, which is remarkably in line with microeconomic evidence in Bertola et al. (2005) (see Figure 7 in Appendix F for a density plot), especially if we consider that the present framework does not feature any adjustment along the extensive margin. In addition, Figure 1 reports the steady-state marginal propensities to consume (MPC) nondurables and durables, as a function of the holdings of liquid assets. Both MPC roughly peak at the point where bond holdings are nil due to the debt cost, as captured by the borrowing wedge, κ. Notice that households with zero liquidity but median holdings of durables can use the durable stock as a consumption-smoothing device (yet, subject to an adjustment cost). As such, durables assume the dual role of a consumption good and of an (illiquid) asset, at the eyes of "wealthy hand-to-mouth" households (see Kaplan et al., 2018). Despite this feature, the MPC is still relatively large for households who are constrained in the access to liquid savings.

At the aggregate level, the model features mean MPC that are empirically realistic. In quarterly terms, this amounts to 12.8% for nondurables and 138.4% for durables, while for total expenditure—the so called MPX, in the taxonomy of Laibson et al. (2022)—the corresponding figure is 76.9%. Thus, the MPC is slightly below the empirical estimates of about 15-25% for nondurables, while the MPX is well within the 50-90% range of the available estimates (Laibson et al., 2022).

Figure 1: Marginal propensities to consume as a function of liquid savings



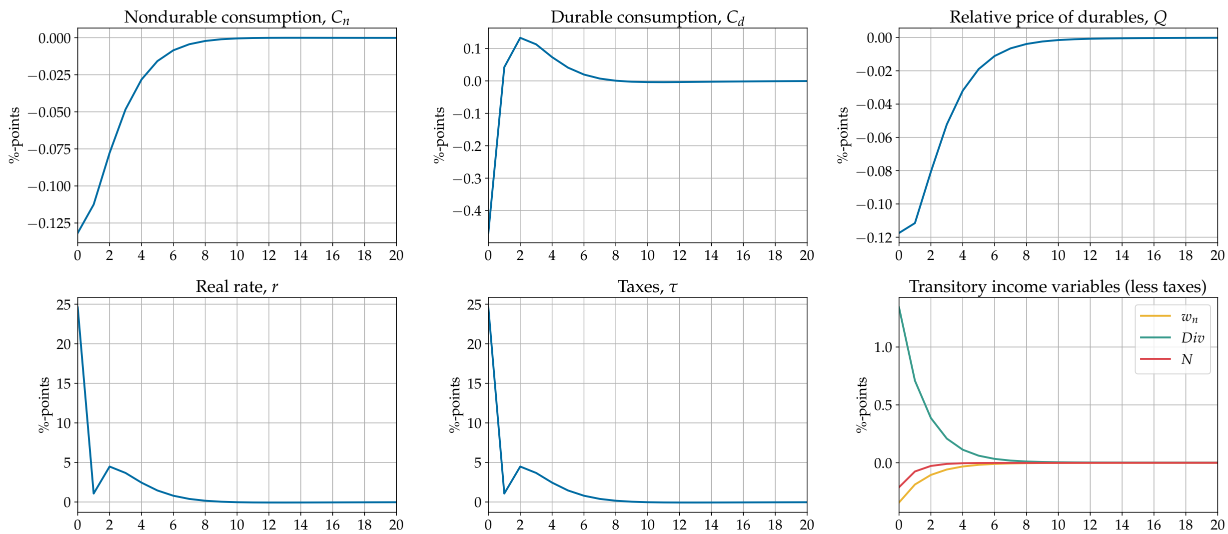
Note: To plot MPCs in two dimensions, we fix the idiosyncratic income shock, $e(s)$, as well as the stock of durables, $D(s)$, at their median steady-state value.

4 Monetary transmission

We are now ready to study monetary transmission, with a special focus on how the response of different types of consumption, both at the aggregate and at the household level, can be decomposed into direct and (different) indirect effects. We then test the robustness of our main insights to accounting for realistic extensions to the original framework.

4.1 Impulse responses to a monetary policy shock

Figure 2: Impulse responses to a contractionary monetary policy shock



Note: We consider a 0.25% monetary-policy innovation occurring at $t = 0$.

To obtain impulse responses, we solve the model to the first order, around the deterministic steady state, using the sequence-space method, as described in Auclert et al. (2021).[7] We consider a monetary policy shock at time $t = 0$. As in Kaplan et al. (2018), we set the quarterly innovation to 0.25%, while the shock-persistence parameter, ρ_{r*}, is set to 0.5.

The results are presented in Figure 2. We may notice how the monetary shock pushes both types of consumption down, with durable expenditure featuring a hump-shaped recovery, as it has typically been shown in both theoretical and empirical settings (see, e.g., Beraja and Wolf, 2021). Also the drop in the relative price is consistent with what expected on *a priori* grounds, given that durables feature relatively more flexible prices. Moreover, the magnitude of the relative price change is relatively modest, as also reported by McKay and Wieland (2021).

The main scope of the subsequent analysis is to study the determinants of the contraction in both types of consumption goods, as well as their relative strength.

[7]For the sequence-space formulation of the model, we refer the reader to Appendix C.

4.2 Consumption decomposition

Following Kaplan et al. (2018), we can decompose the consumption responses as of $t = 0$ into *direct* (i.e., interest-rate) and *indirect* (i.e., general-equilibrium or transitory income) effects, by total differentiation of the impulse-response paths of $\{C_{j,t}\}_{t\geqslant 0}$, for $j = \{n, d\}$:

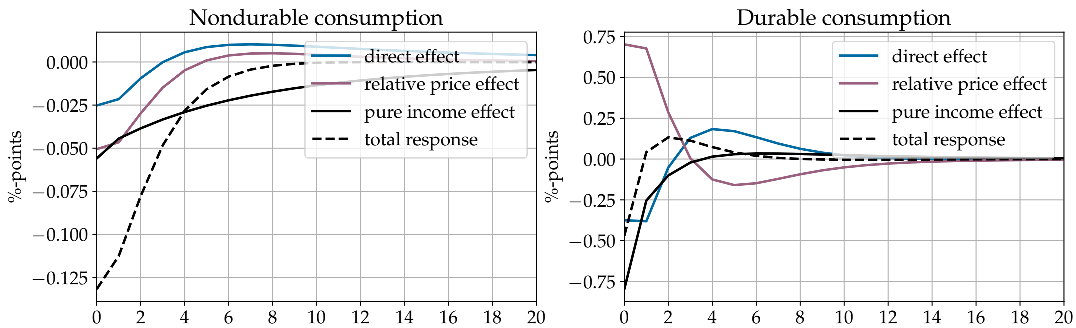
$$dC_{j,0} = \underbrace{\sum_{t=0}^{\infty} \frac{\partial C_{j,0}}{\partial r_t} dr_t}_{\text{direct effect}} + \underbrace{\sum_{t=0}^{\infty} \left(\underbrace{\frac{\partial C_{n,0}}{\partial Q_t} dQ_t}_{\text{relative-price effect}} + \underbrace{\frac{\partial C_{j,0}}{\partial N_t} dN_t + \frac{\partial C_{j,0}}{\partial w_{n,t}} dw_{n,t} + \frac{\partial C_{j,0}}{\partial Div_t} dDiv_t + \frac{\partial C_{j,0}}{\partial \tau_t} d\tau_t}_{\text{pure income effects}} \right)}_{\text{indirect effects}}. \tag{19}$$

Each effect is computed by moving only the variable with respect to which the partial differential is taken. For example, the direct effect is a partial-equilibrium one, whereby all variables other than the real rate are kept fixed. As we are in a two-sector setting, indirect effects can be further grouped into a *relative-price* effect—which embodies both income and substitution effects—and terms that exclusively correspond to *pure income* effects. Numerically, we calculate the partial-equilibrium household paths by varying only the relevant inputs, while keeping the remaining terms fixed. For example, in the case of the direct effect on nondurable consumption, we need to compute

$$\sum_{t=0}^{\infty} \frac{\partial C_{n,0}}{\partial r_t} dr_t = \sum_{t=0}^{\infty} \left(\int \frac{\partial C_{n,0}\left(e_t(s), B_t(s), D_t(s); \{r_t, Q, w_n, N, Div, \tau\}_{t>0}\right)}{\partial r_t} ds \right) dr_t. \tag{20}$$

In practice, this is accomplished by varying one input at a time, given the general-equilibrium path computed through household Jacobians, which are calculated when tackling the sequence-space solution of the impulse-response functions (see Auclert et al., 2021).

Figure 3: Consumption response decomposition



Note: Decomposition of the response of nondurable and durable consumption into direct, relative-price and pure income effects. We consider a 0.25% monetary-policy innovation occurring at $t = 0$.

Figure 3 reports our baseline consumption-response decomposition. This shows how both the direct and pure income effects push both types of consumption down. By contrast, the fall in the relative price would *per se* lead to substitute nondurable for durable consumption, potentially yielding an empirically counterfactual negative comovement. In fact, summing the relative-price to the direct effect would still imply negative comovement between durables and nondurables, as the intratemporal substitution motive—which is driven by the drop in Q_t—is way more powerful than the intertemporal substitution motive, as is typically the case in standard two-sector RANK models. Thus, pure income effects prove key in generating positive consumption comovement.

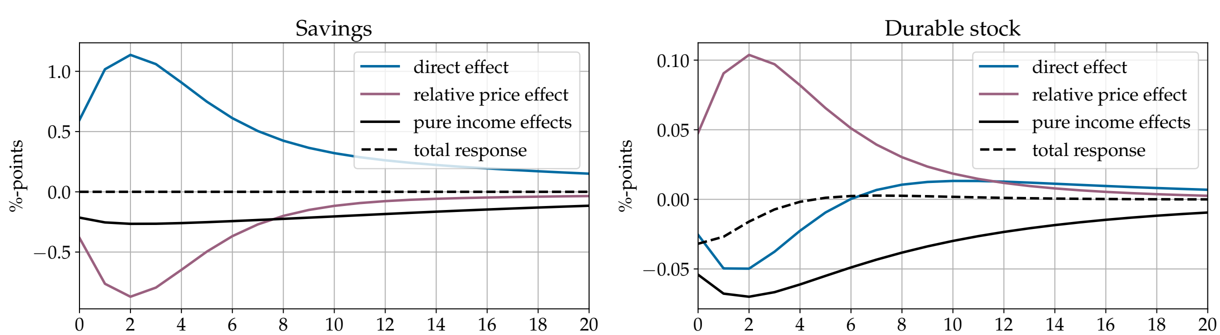
From a quantitative viewpoint, the on-impact interest-rate effect amounts to -0.025 percentage points (pp) for nondurables, while pure income and relative-price effects amount to -0.056 pp and -0.050 pp, respectively. As for durable consumption, the corresponding figures are -0.37 pp, -0.80 pp and 0.70 pp, respectively. Over a year, the contribution of the direct effect is 15% for nondurables and 374% for durables, while the contribution of pure income effects amounts to 47% and 647% for nondurables and durables, respectively.[8] Thus, the contribution of income-related effects to the fall in consumption of both goods is roughly twice as large as that of the direct effect. Looking at the role of the relative price in isolation, instead, we measure a contribution of 38% and -921% for nondurables and durables, respectively.

[8] To establish a term of comparison, in Kaplan et al. (2018), the relative contribution of the direct effect to the response of (nondurable) consumption amounts to about 20% over a year.

Notably, direct, pure income and relative-price effects respectively contribute by 49%, 99% and -48% of the response of aggregate consumption, thus indicating a roughly even contribution of direct and indirect effects to the total consumption response in the baseline two-sector HANK. This implies that transmission through intertemporal substitution re-gains substantial grip, relative to what indicated by one-sector HANK models with nondurables only.

We can further decompose the indirect effects into a variety of sub-components. We do this in Appendix F, Figure 8. Here, we see that the brunt of the negative effect from the income components arises from labor-income variables, N and w_n. Taxes account for a smaller share of the total negative push. The main reason for this is that taxes are progressively distributed according to productivity, so that low-income households—who are more sensitive to transitory income shocks—are partially insulated from this force. From Kaplan et al. (2018), it is well known that the exact assumptions about how the government budget constraint adjusts outside the steady state matter when budgets are balanced period-by-period. In Section 4.3 we show that our set of results still holds in the presence of deficit financing. Moreover, one should recall that dividends are expansionary in the present scenario, as is typically the case in New Keynesian economies featuring rigid prices. In light of this, we argue that ”positive-comovement” forces would be even stronger in a similar model where dividends are procyclical. To test such conjecture, we introduce sticky wages in Section 4.4.

Figure 4: Portfolio-based response decomposition

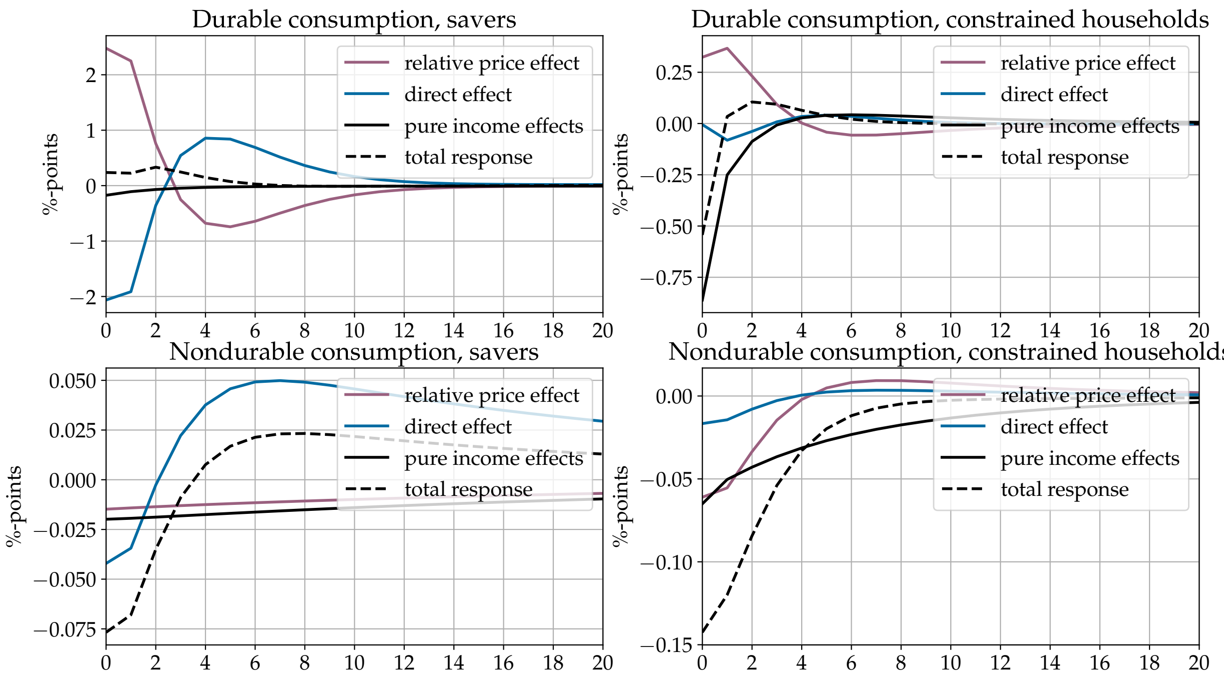


Note: Decomposition of the response of liquid savings and durable consumption into direct, relative-price and pure income effects. We consider a 0.25% monetary-policy innovation occurring at $t = 0$.

A portfolio-based decomposition We should elaborate further on the implications of durables being particularly interest-rate sensitive; a fact that was initially emphasized by Mankiw (1982), among others. In the present setting, a particularly useful perspective to examine this issue consists of considering that, together with liquid assets, durables are implicitly involved in a portfolio allocation choice. Thus, we report a response decomposition of the aggregate *portfolio* featuring bonds and the stock of durables (see Figure 4). Diverging effects of an increase in the interest rate on the holdings of the two assets are to be ascribed to the relative behavior of their rates of return: as the "spread" between these increases, households are progressively induced to tilt their portfolio towards bonds. An opposite force emanates from the relative price of durables, whose contraction would *per se* induce a substitution from bonds towards durables. Pure income effects, instead, are contractionary with respect to both forms of assets. In sum, whereas the overall impact is nil for bonds—by virtue of market clearing—the stock of durables contracts, primarily due to pure income effects.

A wealth-based decomposition We go even deeper in examining the role of different transmission channels, decomposing the consumption responses of liquidity-constrained and unconstrained households. Specifically, the first row of Figure 5 reports durable-consumption decompositions for households at the bottom 50% steady-state bond holdings (i.e., most of the liquidity-constrained households) and for households at the steady-state top 1% of bond holdings (i.e., savers). We see that savers are quite interest-rate sensitive, given their motive to re-balance their portfolio of assets, moving away from durables and towards bonds. Instead, liquidity-constrained households respond very little to interest-rate changes, as expected in light of their hand-to-mouth behavior. Savers' response with respect to durable consumption is also more sensitive to the change in the relative price, to the point that this overcomes the contractionary force exerted by intertemporal substitution. As for liquidity-constrained households', instead, the impact of the relative price on their durable consumption is relatively muted, both because these agents are limited in portfolio reallocation, and because the fall in Q_t entails a conspicuous negative income effect. On the other hand, the fall in the relative price reflects a sizeable compression of hand-to-mouth consumers' nondurable consumption (second row of the figure): on impact, this effect is comparable with that emanating from other determinants of disposable income, which are by far the major drivers of the conditional response of both durables and nondurables, for this class of households.[9] The overall picture emerging from these "household-level" decompositions is that negative comovement between durable and nondurable consumption appears as a distinctive trait of savers' consumption response in the face of a monetary disturbance. By contrast, constrained agents display positive conditional comovement through marked pure income effects, a property that makes these agents and their consumption habits decisive for resolving the comovement puzzle.

Figure 5: Consumption response decomposition by steady-state wealth percentiles



Note: Decomposition of nondurable and durable consumption responses into direct, relative-price and pure income effects, for households differing with respect to their holdings of liquid assets. Liquidity-constrained households are defined as households at the bottom 50% steady-state bond holdings. Savers are defined as households at the steady-state top 1% bond holdings. The effects are calculated using the (initially) truncated distributions relative to a simulation of the relevant truncated distribution conditional on all input variables being at their steady-state values. We consider a 0.25% monetary-policy innovation occurring at $t = 0$.

[9]By contrast, savers' nondurable consumption response is poorly shaped by indirect effects, all in all. In this respect, recall that assuming a unit relative risk aversion implies that the relative price does not affect unconstrained households' nondurable consumption through substitution effects.

4.3 Deficit financing

It is well known that the specific assumptions about how the government budget constraint adjusts outside the steady state matter in HANK economies, especially when governments balance their budget period-by-period. As mentioned in Section 4.2, part of the positive consumption comovement accomplished through pure income effects is driven by the tax increase. Thus, to test the robustness of this result, we neutralize movements in taxes by replacing equation (13) with (21), as in Auclert et al. (2020b):

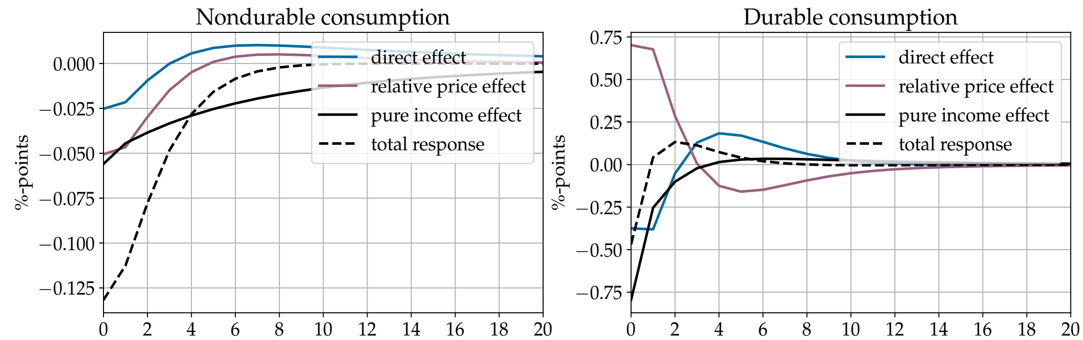
$$\begin{aligned}(1+r_t)\,B^g_{t-1} &= \tau_t + B^g_t,\\ \tau_t &= \tau + \phi_\tau\left(B^g_{t-1} - B^g\right),\end{aligned} \tag{21}$$

where τ and B^g denote steady-state taxes and government bonds, respectively, while ϕ_τ determines how fast deficits are closed. Note that such formulation does not affect the steady state. Outside the steady state, we find taxes in each period conditional on the government budget constraint holding; see Appendix D for further details.

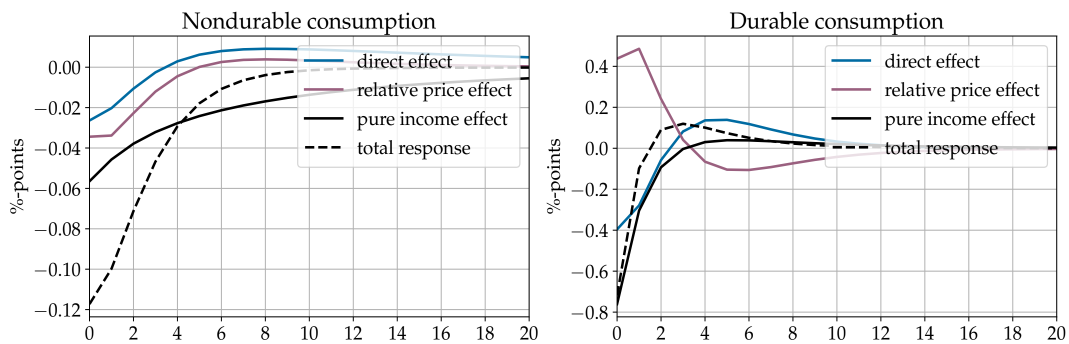
Re-calibration We set ϕ_τ to 0.1, as in Auclert et al. (2020b). Note that, under deficit financing, we need to re-perform our SMM calibration exercise for the scaling parameter in the adjustment cost of durables and the price adjustment costs, so as to target the volatility of durables to nondurables. Doing so results in $\alpha = 0.137$, while the Calvo probability amounts to 0.62 for nondurables and 0.40 for durables, thus mapping into $\xi_n = 19.90$ and $\xi_d = 8.37$, respectively. The discount factor, β, is now 0.965, the borrowing wedge, κ, is 0.0454, while the total factor productivities of nondurable and durable production are 1.0 and 2.15, respectively. Finally, the scaling parameter for labor disutility, ψ_N, is 0.765. The resulting volatility of durables-to-nondurables is 3.563, while steady-state ratio between nondurable to total consumption is 0.60 (implying γ=0.4), in line with the baseline calibration.

Consumption decomposition The second row of Figure 6 contains a consumption decomposition of the effects induced by a monetary tightening in the presence of fiscal deficits, in line with the analogous decomposition for the baseline model in Section 4.2

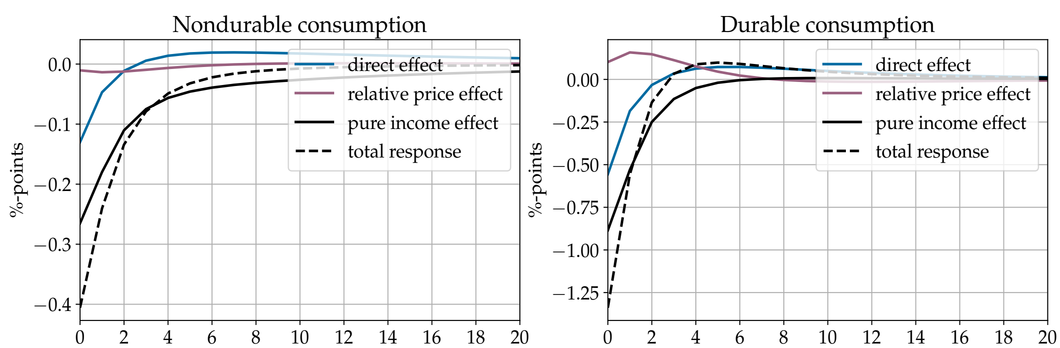
Figure 6: Consumption response decomposition, robustness to different model alterations



(a) Baseline model



(b) Deficit financing



(c) Sticky wages

Note: Decomposition of the response of nondurable and durable consumption into direct, relative-price and pure income effects. Top panel: baseline model; middle panel: model with deficit financing; bottom panel: model with sticky wages. We consider a 0.25% monetary-policy innovation occurring at $t = 0$.

(which has been reproduced in the first row of the figure, to enhance comparability). Even with fiscal deficit financing, pure income effects still drive the brunt of the contractionary response of both types of consumption goods. For a more detailed view, we refer the reader to Figure 9 in Appendix F. As expected, taxes barely move in the presence of deficit financing.

4.4 Sticky wages

It is well known that sticky wages alleviate the issue of countercyclical profits. In addition, they also reinforce durable and nondurable consumption comovement, as sticky wages dampen relative-price changes (see Carlstrom and Fuerst, 2010). Given these reasonable properties, we extend our HANK model to accommodate sticky wages. The twist consists of replacing the wage schedule equation, (4), with a wage Phillips curve as in Erceg et al. (2000), Erceg and Levin (2006) and Hagedorn et al. (2019). To this end, we assume that each household provides differentiated labor services that transformed into aggregate effective labor by perfectly competitive labor packers. In turn, a union sells labor services at the nominal wage W_t (equalized across production sectors) to the labor recruiter, who minimizes costs given the aggregate demand for labor. In doing so, the union sets the nominal wage for one effective labor unit subject to virtual Rotemberg adjustment costs. Further analytical details on the modeling approach are reported in Appendix G.

Re-calibration Given this extended structure, we need to re-calibrate some parameters. We set $\xi_n = 54.42$ and $\xi_d = 2.20$, such that the corresponding Calvo probabilities for prices are right on target (i.e, 0.75 and 0.25, respectively). As for wage stickiness, we set $\xi_w = 54.42$ to target a Calvo probability of 0.75, yielding an implied duration of wage contracts of one year, in line with the estimates of Smets and Wouters (2003) and Levin et al. (2005). We re-calibrate the parameter scaling the adjustment of durables, α, to 1.522, so as to target the relative (on-impact) volatility of C_d to C_n. The model can now hit that target of 3.572 with precision. The borrowing wedge, κ, is re-calibrated to 0.0368, to targewet a 30% steady-state share of liquidity-constrained households. The discount factor, β, is now 0.9634. The scaling of labor disutility, ψ_N, is 0.633. Finally, the implied steady-state total factor productivity in each sector are $A_n = 1$ and $A_d = 2.58$, while steady-state nondurable-to-total consumption, $C_n/(C_n+C_d)$, equals 0.61 (so that $\gamma = 0.39$). Finally, we set the labor unions' market power in line with that characterizing the two intermediate-goods markets, so that $\epsilon_w = \epsilon_n = \epsilon_d = 0.6$.

Consumption decomposition The last row of Figure 6 reports a consumption decomposition for the model with sticky wages. In this case, pure income effects make up an even larger part of the consumption response. This is because prices inherit some stickiness from wages, causing relative-price movements to be smaller, thus alleviating dividend countercyclicality.[10] It should be stressed, however, that durables are still quite interest-rate sensitive: over a year, the relative contribution of the interest rate to the drop in sectoral consumption is 21% for nondurables and 37% for durables. The corresponding figures for pure income effects are 73% and 89%, respectively, while the relative-price effect alone accounts for 5% and -26% of the responses, respectively. As for the response of total consumption, we have a contribution of 26%, 75% and -0.01% from direct, pure income and relative-price effects, respectively. It is also important to stress that the main takeaways from the wealth-based decomposition in Section 4.2 carry over to the present setting. That is: *i*) savers are those whose durable consumption is more sensitive to interest-rate effects, and the overall response of their durable and nondurable consumption displays negative comovement; *ii*) the aggregate relevance of pure income effects is due to the hand-to-mouth behavior of liquidity-constrained households, whose consumption of either type of good comoves positevely, conditional on the shock, thus being decisive for resolving the comovement puzzle.[11]

5 Concluding remarks

We introduce durable goods into an otherwise standard New Keynesian model with heterogeneous households, showing how pure income effects dominate the consumption response of both nondurables and durables to a monetary policy shock, and are key to undoing negative comovement arising from changes in the relative price of the two goods.

[10]For a detailed account, see Appendix F, Figure 10.

[11]Both of these facts are documented in Appendix F, Figure 11.

Concurrently, we confirm that durables are more interest-rate sensitive than non-durables and, most importantly, show that interest-rate effects make up a sizable fraction of the total response of both durables and aggregate consumption to monetary policy shocks. This indicates that changes in conventional policy instruments have a grip that is typically downplayed by analyses that limit their focus to one-sector HANK economies. Considering the dominant impact of durables on business-cycle volatility, and specifically on the transmission of monetary shocks, it is essential to consider the lessons learned in this paper for understanding and designing monetary policy.

References

Albouy, D., Ehrlich, G., and Liu, Y. (2016). Housing demand, cost-of-living inequality, and the affordability crisis. *NBER Working Paper Series*, pages 22816–.

Alves, F., Kaplan, G., Moll, B., and Violante, G. L. (2020). A Further Look at the Propagation of Monetary Policy Shocks in HANK. *Journal of Money, Credit and Banking*, 52(S2):521–559.

Auclert, A. (2019). Monetary Policy and the Redistribution Channel. *American Economic Review*, 109(6):2333–2367.

Auclert, A., Bardóczy, B., and Rognlie, M. (2020a). MPCs, MPEs and Multipliers: A Trilemma for New Keynesian Models.

Auclert, A., Bardóczy, B., Rognlie, M., and Straub, L. (2021). Using the Sequence-Space Jacobian to Solve and Estimate Heterogeneous-Agent Models. *Econometrica*, 89(5):2375–2408.

Auclert, A., Rognlie, M., and Straub, L. (2020b). Micro Jumps, Macro Humps: Monetary Policy and Business Cycles in an Estimated HANK Model.

Barsky, R. B., House, C. L., and Kimball, M. S. (2007). Sticky-Price Models and Durable Goods. *American Economic Review*, 97(3):984–998.

Beraja, M. and Wolf, C. K. (2021). Demand Composition and the Strength of Recoveries.

Berger, D. and Vavra, J. (2015). Consumption Dynamics During Recessions. *Econometrica*, 83(1):101–154.

Bertola, G., Guiso, L., and Pistaferri, L. (2005). Uncertainty and Consumer Durables Adjustment. *The Review of Economic Studies*, 72(4):973–1007.

Carlstrom, C. and Fuerst, T. (2010). Nominal rigidities, residential investment, and adjustment costs. *Macroeconomic Dynamics*, 14(1):136–148.

Davis, M. A. and Ortalo-Magné, F. (2011). Household expenditures, wages, rents. *Review of economic dynamics*, 14(2):248–261.

Debortoli, D. and Galí, J. (2021). Monetary policy with heterogeneous agents: Insights from TANK models. Technical Report 1686, Department of Economics and Business, Universitat Pompeu Fabra. Publication Title: Economics Working Papers.

Dey, J. and Tsai, Y.-C. (2012). Explaining the durable goods co-movement puzzle with non-separable preferences: a bayesian approach. Technical Report 57805, University Library of Munich, Germany. Publication Title: MPRA Paper.

Erceg, C. and Levin, A. (2006). Optimal monetary policy with durable consumption goods. *Journal of Monetary Economics*, 53(7):1341–1359.

Erceg, C. J., Henderson, D. W., and Levin, A. T. (2000). Optimal monetary policy with staggered wage and price contracts. *Journal of Monetary Economics*, 46(2):281–313.

Hagedorn, M., Manovskii, I., and Mitman, K. (2019). The Fiscal Multiplier.

Harmenberg, K. and Öberg, E. (2021). Consumption dynamics under time-varying unemployment risk. *Journal of Monetary Economics*, 118:350–365.

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

Katayama, M. and Kim, K. H. (2013). The delayed effects of monetary shocks in a two-sector New Keynesian model. *Journal of Macroeconomics*, 38:243–259.

Laibson, D., Maxted, P., and Moll, B. (2022). A simple mapping from mpcs to mpxs. *NBER Working Paper Series*.

Levin, A. T., Onatski, A., Williams, J. C., and Williams, N. (2005). Monetary Policy under Uncertainty in Micro-Founded Macroeconometric Models. *NBER Macroeconomics Annual*, 20:229–287. Publisher: University of Chicago Press.

Mankiw (1982). Hall's Consumption Hypothesis and Durable Goods. *Journal of Monetary Economics*, 10(Nov):417–426.

Mankiw, N. G. (1985). Consumer Durables and the Real Interest Rate. *The Review of Economics and Statistics*, 67(3):353–362.

McKay, A., Nakamura, E., and Steinsson, J. (2016). The Power of Forward Guidance Revisited. *American Economic Review*, 106(10):3133–3158.

McKay, A. and Wieland, J. F. (2021). Lumpy Durable Consumption Demand and the Limited Ammunition of Monetary Policy. *Econometrica*, 89(6):2717–2749.

McKay, A. and Wieland, J. F. (2022). Forward Guidance and Durable Goods Demand. *American Economic Review: Insights*, 4(1):106–122.

Monacelli, T. (2009). New Keynesian models, durable goods, and collateral constraints. *Journal of Monetary Economics*, 56(2):242–254.

Nakamura, E. and Steinsson, J. (2008). Five Facts about Prices: A Reevaluation of Menu Cost Models*. *The Quarterly Journal of Economics*, 123(4):1415–1464.

Ogaki, M. and Reinhart, C. (1998). Measuring intertemporal substitution: The role of durable goods. *The Journal of political economy*, 106(5):1078–1098.

Pakos, M. (2011). Estimating intertemporal and intratemporal substitutions when both income and substitution effects are present: The role of durable goods. *Journal of business economic statistics*, 29(3):439–454.

Petrella, I., Rossi, R., and Santoro, E. (2019). Monetary Policy with Sectoral Trade-Offs. *Scandinavian Journal of Economics*, 121(1):55–88.

Smets, F. and Wouters, R. (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association*, 1(5):1123–1175.

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

Sudo, N. (2012). Sectoral Comovement, Monetary Policy Shocks, and Input-Output Structure. *Journal of Money, Credit and Banking*, 44(6):1225–1244.

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

Tsai, Y.-C. (2016). What Do Working Capital And Habit Tell Us About The Co-Movement Problem? *Macroeconomic Dynamics*, 20(1):342–361.

Young, E. R. (2010). Solving the incomplete markets model with aggregate uncertainty using the Krusell–Smith algorithm and non-stochastic simulations. *Journal of Economic Dynamics and Control*, 34(1):36–41.

Appendix

A Endogenous grid method with non-separable utility in durable and nondurable consumption

A.1 Model setup

Households face the following optimization problem:

$$\begin{aligned} V_t\left(z_t, b_t, d_t\right) = \max_{c_t, d_{t+1}, b_{t+1}} u\left(c_t, d_t\right) + \beta \mathbb{E}_t V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right) \\ \text{s.t. } c_t + b_{t+1} + Q_t\left(d_{t+1} - (1-\delta)d_t\right) = z_t + \left(1 + r_t\right) b_t - \Psi\left(d_{t+1}, d_t\right) \\ b_t \geqslant \underline{b}, \quad d_t \geqslant 0, \end{aligned} \tag{22}$$

where z_t denotes idiosyncratic income, b_t is wealth, d_t denotes durables and Q_t is the price of durables relative to that of nondurables. In the general equilibrium setting, $z_t = \exp\{e_t\}\left[w_{n,t}N_t - \tau_t + Div_t\right]$. The rest, except for utility and the cost function $\Psi(\cdot)$ is standard. The utility and the adjustment cost functions are

$$\begin{aligned} u(c_t, d_t) = \tfrac{\psi(c_t, d_t)^{1-\sigma}}{1-\sigma} \quad \text{and} \quad \psi(c_t, d_t) = c_t^{\theta} d_t^{1-\theta}, \\ \Psi\left(d_{t+1}, d_t\right) = \tfrac{\alpha}{2}\left(\tfrac{d_{t+1} - (1-\delta)d_t}{d_t}\right)^2 d_t. \end{aligned} \tag{23}$$

A.2 First-order and envelope conditions

Re-write the Bellman equation by substituting out consumption using the budget constraint

$$\begin{aligned} V_t\left(z_t, b_t, d_t\right) = \max\nolimits_{b_{t+1}, d_{t+1}} \quad & u\left(z_t + \left(1 + r_t\right) b_t - Q_t\left(d_{t+1} - (1-\delta)d_t\right) - \Psi\left(d_{t+1}, d_t\right) - b_{t+1}, d_t\right) \\ & + \mu_t d_{t+1} + \lambda_t\left(b_{t+1} - \underline{b}\right) + \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right), \end{aligned} \tag{24}$$

where μ_t and λ_t are the multipliers for the non-negativity constraint on durables and the unsecured credit-borrowing constraint, respectively.

The first-order conditions with respect to d_{t+1} and b_{t+1} yield

$$\begin{aligned} \partial_{c_t} u(c_t, d_t)\left(Q_t + \partial_{d_{t+1}} \Psi\left(d_{t+1}, d_t\right)\right) &= \mu_t + \partial_{d_{t+1}} \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right), \\ \partial_{c_t} u(c_t, d_t) &= \lambda_t + \partial_{b_{t+1}} \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right). \end{aligned} \tag{25}$$

The envelope conditions are

$$\begin{aligned} \partial_{b_t} V_t\left(z_t, b_t, d_t\right) &= \left(1 + r_t\right) \partial_c u(c_t, d_t), \\ \partial_{d_t} V_t\left(z_t, b_t, d_t\right) &= \partial_{d_t} u(c_t, d_t) + \partial_{c_t} u(c_t, d_t)\left[Q(1-\delta) - \partial_{d_t} \Psi\left(d_{t+1}, d_t\right)\right]. \end{aligned} \tag{26}$$

For later use, it is convenient to define the post-decision value function as

$$W_t\left(z_t, b_{t+1}, d_{t+1}\right) \equiv \beta \mathbb{E}_t V_{t+1}\left(z_t, b_{t+1}, d_{t+1}\right). \tag{27}$$

A.3 Main equations of the algorithm

First, we combine the equations in (25) to obtain

$$\frac{\mu_t + \partial_d \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right)}{\lambda_t + \partial_b \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right)} = Q_t + \alpha\left(\frac{d_{t+1}}{d_t} - (1-\delta)\right). \tag{28}$$

From the F.O.C. wrt. b_{t+1} in (25) we can pin down nondurable consumption:

$$\begin{aligned} \tfrac{\partial u(c_t, d_t)}{\partial c_t} &= \lambda_t + \partial_{a_{t+1}} \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right) \\ \Rightarrow \theta c_t^{\theta-1} d_t^{1-\theta}\left[c_t^{\theta} d_t^{1-\theta}\right]^{-\sigma} &= \lambda_t + \partial_{b_{t+1}} \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right) \\ \Rightarrow c_t &= \left[\tfrac{1}{\theta}\left(\lambda_t + \partial_{b_{t+1}} \beta \mathbb{E} V_{t+1}\left(z_{t+1}, b_{t+1}, d_{t+1}\right)\right) d_t^{(\theta-1)(1-\sigma)}\right]^{\frac{1}{\theta(1-\sigma)-1}}. \end{aligned} \tag{29}$$

A.4 Algorithm

The algorithm is based on the two-asset algorithm described in Auclert et al. (2021). For a generic variable x_t, denote today's grid by x and tomorrow's grid by $x^{'}$. Thus, according to the EGM algorithm:

1. When seeking for steady-state policies, initialize the guess on $\partial_b V\left(z,b,d\right), \partial_d V\left(z,b,d\right)$. Otherwise, start backward induction by using steady-state $\partial_b V\left(z,b,d\right), \partial_d V\left(z,b,d\right)$ (used when calculating household Jacobians).

2. Let the productivity-shock transmission matrix be notated by Π. The value functions have a common $z' \rightarrow z$ so the post-decision functions are:
$$\begin{aligned} W_b\left(z,b',d'\right) &= \beta\Pi V_b\left(z',b',d'\right), \\ W_d\left(z,b',d'\right) &= \beta\Pi V_d\left(z',b',d'\right). \end{aligned} \tag{30}$$

3. Find $d'(z,b',d)$ for the *unconstrained* case using eq. (28):
$$\frac{W_d\left(z,b',d'\right)}{W_b\left(z,b',d'\right)} = Q + \alpha\left(\frac{d'}{d} - (1-\delta)\right). \tag{31}$$

4. Use $d'(z,b',d)$ to map $W_b\left(z,b',d'\right)$ into $W_b\left(z,b',d\right)$ by interpolation. Then compute consumption by using (29):
$$c(z,b',d) = \left(W_b\left(z,b',d\right) d^{\theta-1} \cdot d^{(1-\theta)\sigma}\right)^{\frac{1}{\theta(1-\sigma)-1}}. \tag{32}$$

5. Now it is possible to find total assets by inserting $d'(z,b',d)$ and $c(z,b',d)$ into the budget constraint:
$$b\left(z,b',d\right) = \frac{c\left(z,b',d\right) + Q\left(d'\left(z,b',d\right) - (1-\delta)\,d\right) + b' + \Psi\left(d'(z,b',d),d\right) - z}{1+r}. \tag{33}$$

6. Invert $b\left(z,b',d\right)$ to obtain $b'\left(z,b,d\right)$ by interpolation. Use the same interpolation weights to obtain $d'(z,b,d)$.

7. Find $d'(z,\underline{b},d)$ for the *constrained* case using eq. (28). For scaling, define $\kappa \equiv \lambda / W_b\left(z,\underline{b},d'\right)$.

Then eq. (28) becomes

$$\frac{1}{1+\kappa}\frac{W_d\left(z,\underline{b},d'\right)}{W_b\left(z,\underline{b},d'\right)}=Q+\alpha\left(\frac{d'}{d}-(1-\delta)\right). \tag{34}$$

8. Use eq. (34) to solve for $d'(z,\kappa,d)$, that is over a grid of κ values. Then compute consumption as

$$c(z,\kappa,d)=\left((1+\kappa)W_b\left(z,\kappa,d\right)d^{\theta-1}\cdot d^{(1-\theta)\sigma}\right)^{\frac{1}{\theta(1-\sigma)-1}}. \tag{35}$$

9. Using $d'(e,\kappa,d)$, $c(e,\kappa,d)$ and the budget constraint obtain

$$b(z,\kappa,d)=\frac{c(z,\kappa,d)+Q\left(d'(z,\kappa,d)-(1-\delta)\,d\right)+\underline{b}+\Psi\left(d'(z,\kappa,d),d\right)-z}{1+r}. \tag{36}$$

10. Invert $b(z,\kappa,d)$ by interpolation to obtain $\kappa(z,b,d)$. The same interpolation weights can be used to map $d'(z,\kappa,d)$ into $d'(z,b,d)$. By definition, $b'(z,b,d)=\underline{b}$.

11. Combine the constrained and the unconstrained solutions of $b'(z,b,d)$ and $d'(z,b,d)$. Then compute consumption from the budget constraint:

$$c(z,b,d)=z+(1+r)\,b-Q\left(d'(z,b,d)-(1-\delta)\,d\right)-\Psi\left(d',d\right)-b'(z,b,d). \tag{37}$$

12. Update $\partial_b V\left(z,b,d\right)$ and $\partial_d V\left(z,b,d\right)$ using the envelope conditions from (26):

$$\begin{aligned}\partial_b V\left(z,b,d\right)&=(1+r)\,\partial_c u(c,d),\\ \partial_d V\left(z,b,d\right)&=\partial_d u(c,d)-\partial_c u(c,d)\left[Q(1-\delta)+\partial_d\Psi\left(d',d\right)\right].\end{aligned} \tag{38}$$

13. For the steady-state solutions: Return to step 2 and follow the same steps until the change in $\partial_b V\left(z,b,d\right)$ and $\partial_d V\left(z,b,d\right)$ between iterations is ≈ 0. Otherwise, solve paths by backward iteration (used to obtain household Jacobians given some shock to a given household input variable).

Finally, to obtain aggregates we need to simulate the distribution of households. We use the histogram method as developed in Young (2010). In the steady state, we simulate forwards until the change in the distribution between iterations is ≈ 0. Outside the steady state, one can simply simulate forward given a path length.

B Deterministic steady state

The distribution is obtained by relying on the deterministic histogram method of Young (2010). Given guesses for β, Q, N_d, we can solve for equilibrium quantities as follows:

1. We set $P_n = 1$ as the numeraire, so that $\Pi_n = 1$;
2. We get that $\Pi_d = 1$, as $\Pi_d = \Pi_n$ in the steady state;
3. Given a calibration target for Y_d (which is set to 0.5), we pin down $A_d = Y_d/N_d$;[12]
4. We obtain $w_d = A_d \cdot \frac{\epsilon_d - 1}{\epsilon_d}$ from the durable-goods sector Phillips curve;
5. The latter then yields real wage in the nondurable-goods sector as $w_n = Q \cdot w_d$, as the nominal wage is equalized across sectors;
6. From the nondurable-goods sector Phillips curve we can pin down $A_n = w_n \cdot \frac{\epsilon_n}{\epsilon_n - 1}$;
7. We set $Y_n = 1 - Q \cdot Y_d$, such that total output, $Y = 1$;
8. We then obtain employment in the nondurable-goods sector as $N_n = Y_n/A_n$;
9. We get dividends from (11), $Div(Y_n, Y_d, Q, w_n, w_d)$;
10. Taxes are pinned down as $\tau = r \cdot B^g$.

As we pin down all variables from aggregate relationships, it is then possible to solve the household problem to obtain C_n, C_d, B, and check root-finding target residuals. Thus, after root-finding, we set ψ_N given w_n, C_n, C_d and the parameters, such that the wage schedule, eq. (4), holds in the steady state.

[12] $Y_d = 0.5$ is a reasonable choice—given that $Y_d = C_d$—as C_d makes up a empirically plausible share of total consumption; cf. the calibration target for $C_n/(C_n + C_d)$.

C Sequence space formulation for impulse responses

In sequence space, the model can be summarized by the equation system

$$H\left(N_{n,t}, N_{d,t}, \Pi_{n,t}, Q_t, w_{n,t}, u_t^r\right) = \begin{pmatrix} \text{Wage schedule} \\ \text{NKPC durables} \\ \text{NKPC nondurables} \\ \text{Bonds market} \\ \text{Goods market durables} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{39}$$

Denoting aggregate solution variables with $\mathcal{B}, \mathcal{C}_n$,$\mathcal{C}_d$,$\mathcal{D}$, the system can be reported as

$$\begin{gathered} H\left(N_{n,t}, N_{d,t}, \Pi_{n,t}, Q_t, w_{n,t}, u_t^r\right) = \\ \begin{pmatrix} w_{n,t} - \psi_N N_t^{\varphi} \frac{1}{\theta}\left(\mathcal{C}_{n,t}^{\theta}\mathcal{D}_t^{1-\theta}\right)^{\sigma}\left(\frac{\mathcal{C}_{n,t}}{\mathcal{D}_t}\right)^{1-\theta} \\ (1-\epsilon_d) + \epsilon_d w_{d,t}/A_n - \xi_d\left(\Pi_{d,t}-1\right)\Pi_{d,t} + \beta\xi_d\left(\Pi_{d,t+1}-1\right)\Pi_{d,t+1}\frac{Y_{d,t+1}}{Y_{d,t}} \\ (1-\epsilon_n) + \epsilon_n w_{n,t}/A_d - \xi_n\left(\Pi_{n,t}-1\right)\Pi_{n,t} + \beta\xi_n\left(\Pi_{n,t+1}-1\right)\Pi_{n,t+1}\frac{Y_{n,t+1}}{Y_{n,t}} \\ \mathcal{B}_t - B^g \\ Y_{d,t} - \mathcal{C}_{d,t} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \end{gathered} \tag{40}$$

where we have

$$\Pi_{d,t} = \frac{Q_t}{Q_{t-1}}\Pi_{n,t} \tag{41}$$

$$Y_{n,t} = A_n N_{n,t} \tag{42}$$

$$Y_{d,t} = A_d N_{d,t} \tag{43}$$

$$N_t = N_{n,t} + N_{d,t} \tag{44}$$

$$w_{d,t} = Q_t^{-1} w_{n,t} \tag{45}$$

$$Div_t = Y_{n,t} - w_{n.t} N_{n,t} + Q_t \left[Y_{d,t} - w_{d,t} N_{d,t} \right] \tag{46}$$

$$\tilde{\Pi}_t = \Pi_{n,t}^{1-\gamma} \Pi_{d,t}^{\gamma} \tag{47}$$

$$i_t = u_t^r + \phi_{\tilde{\pi}} \tilde{\pi}_t \tag{48}$$

$$r_t = \frac{1 + i_{t-1}}{1 + \pi_{n,t}} - 1 \tag{49}$$

$$\tau_t = r_t B_g \tag{50}$$

and where the market for nondurable goods clears by Walras' law.

D Sequence space formulation with deficit financing

All targets and variables stay the same as in Appendix C. The only difference is that we replace (50) with

$$\tau_t = \tau + \phi_\tau \left(B_{t-1}^g - B^g \right), \tag{51}$$

where it has to hold that

$$\left(1 + r_t\right) B_{t-1}^g = \tau_t + B_t^g. \tag{52}$$

Thus, we use a root-finder to solve for the path of B_t^g consistent with (52), nested in the sequence space formulation. For further details, see Appendix C.5 in Auclert et al. (2021). The model can the be solved in sequence space, as described in Appendix C.

E Sequence space formulation with sticky wages

In sequence space, the model with the wage Phillips curve can be summarized by the equation system

$$H\left(N_{n,t}, N_{d,t}, \Pi_{n,t}, Q_t, w_{n,t}, u_t^r\right) = \begin{pmatrix} \text{Wage Phillips curve} \\ \text{Phillips curve durables} \\ \text{Phillips curve nondurables} \\ \text{Bonds market clearing} \\ \text{Durable goods market clearing} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{53}$$

Using caligraphic variables $\mathcal{B}, \mathcal{C}_n$,$\mathcal{C}_d$,$\mathcal{D}$ to denote the aggregated household solution variables counterparts, the system reads as

$$H\left(N_{n,t}, N_{d,t}, \Pi_{n,t}, Q_t, w_{n,t}, u_t^r\right) =$$
$$\begin{pmatrix} \left(1-\epsilon_w\right) w_{n,t} + \epsilon_w \frac{U_N'(N_t)}{U_{C_n}'(\mathcal{C}_{n,t},\mathcal{D}_t)} - \xi_w \left(\Pi_{w,t}-1\right)\Pi_{w,t} + \beta\xi_w\left(\Pi_{w,t+1}-1\right)\Pi_{w,t+1}\frac{N_{t+1}}{N_t} \\ \left(1-\epsilon_d\right) + \epsilon_d w_{d,t}/A_n - \xi_d\left(\Pi_{d,t}-1\right)\Pi_{d,t} + \beta\xi_d\left(\Pi_{d,t+1}-1\right)\Pi_{d,t+1}\frac{Y_{d,t+1}}{Y_{d,t}} \\ \left(1-\epsilon_n\right) + \epsilon_n w_{n,t}/A_d - \xi_n\left(\Pi_{n,t}-1\right)\Pi_{n,t} + \beta\xi_n\left(\Pi_{n,t+1}-1\right)\Pi_{n,t+1}\frac{Y_{n,t+1}}{Y_{n,t}} \\ \mathcal{B}_t - B^g \\ Y_{d,t} - \mathcal{C}_{d,t} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{54}$$

where we have

$$\Pi_{d,t} = \frac{Q_t}{Q_{t-1}}\Pi_{n,t} \tag{55}$$

$$\Pi_{w,t} = \frac{w_{n,t}}{w_{n,t-1}} \cdot \Pi_{n,t} \tag{56}$$

$$Y_{n,t} = A_n N_{n,t} \tag{57}$$

$$Y_{d,t} = A_d N_{d,t} \tag{58}$$

$$N_t = N_{n,t} + N_{d,t} \tag{59}$$

$$w_{d,t} = Q_t^{-1} w_{n,t} \tag{60}$$

$$Div_t = Y_{n,t} - w_{n.t} N_{n,t} + Q_t \left[Y_{d,t} - w_{d,t} N_{d,t} \right] \tag{61}$$

$$\tilde{\Pi}_t = \Pi_{n,t}^{1-\gamma} \Pi_{d,t}^{\gamma} \tag{62}$$

$$i_t = u_t^r + \phi_{\tilde{\pi}} \tilde{\pi}_t \tag{63}$$

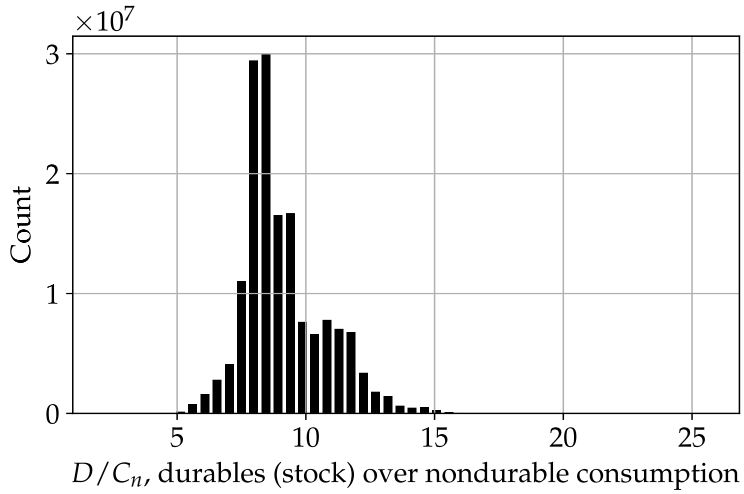
$$r_t = \frac{1 + i_{t-1}}{1 + \pi_{n,t}} - 1 \tag{64}$$

$$\tau_t = r_t B_g \tag{65}$$

and where the nondurable goods market clears by Walras' law.

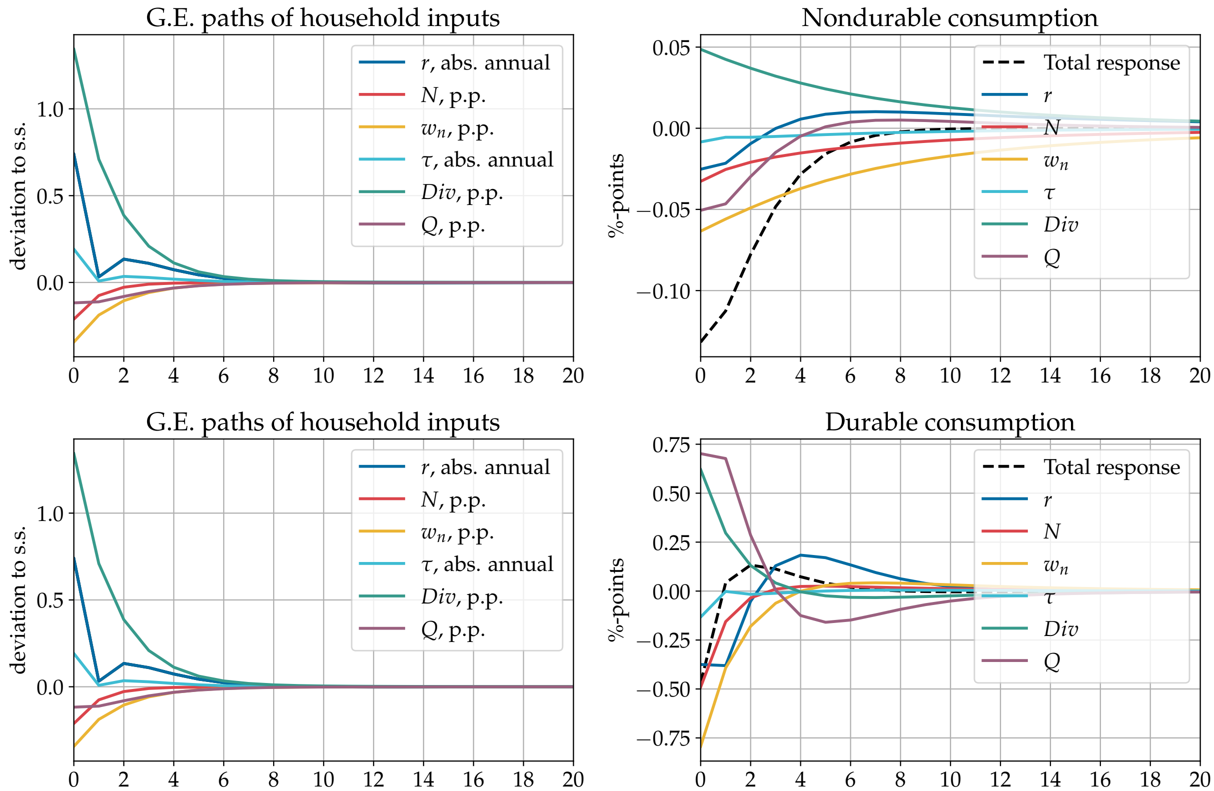
F Additional figures

Figure 7: Steady-state histogram of durables (stock) to nondurable consumption



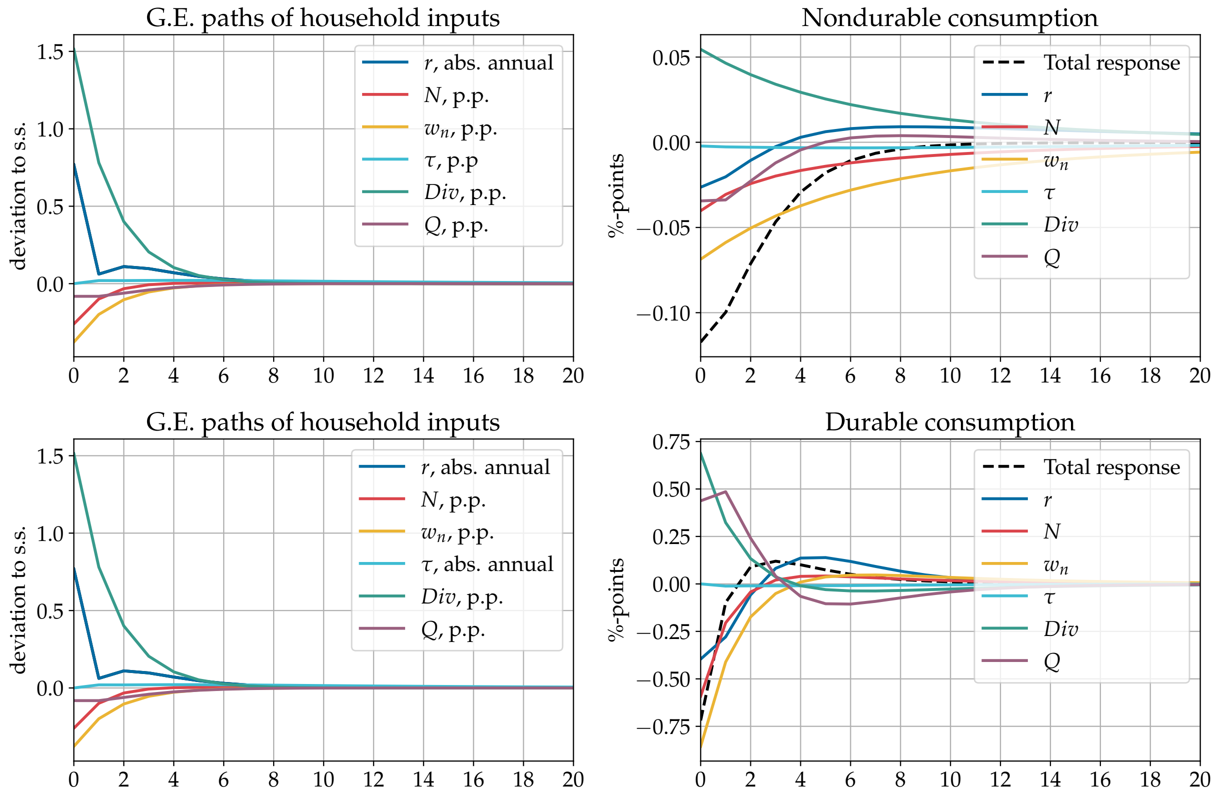
Note: To generate the histogram, we Monte Carlo simulate the steady-state household distribution using 2D linear interpolation over policy functions. We simulate 80.000 households for 2.000 periods and discard the first 1.000 periods. We use 50 bins for plotting.

Figure 8: Detailed consumption response decomposition



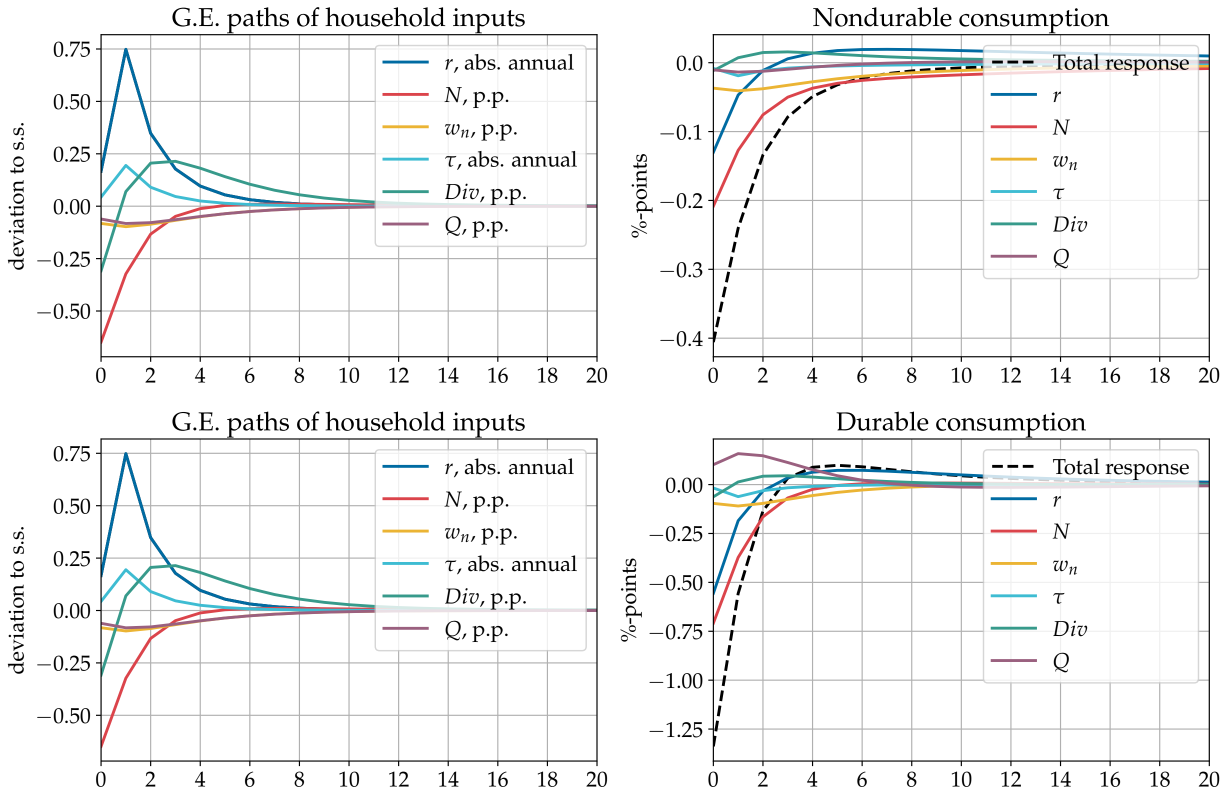
Note: Absolute annual deviations are calculated for visualization purposes.

Figure 9: Detailed consumption response decomposition under deficit financing



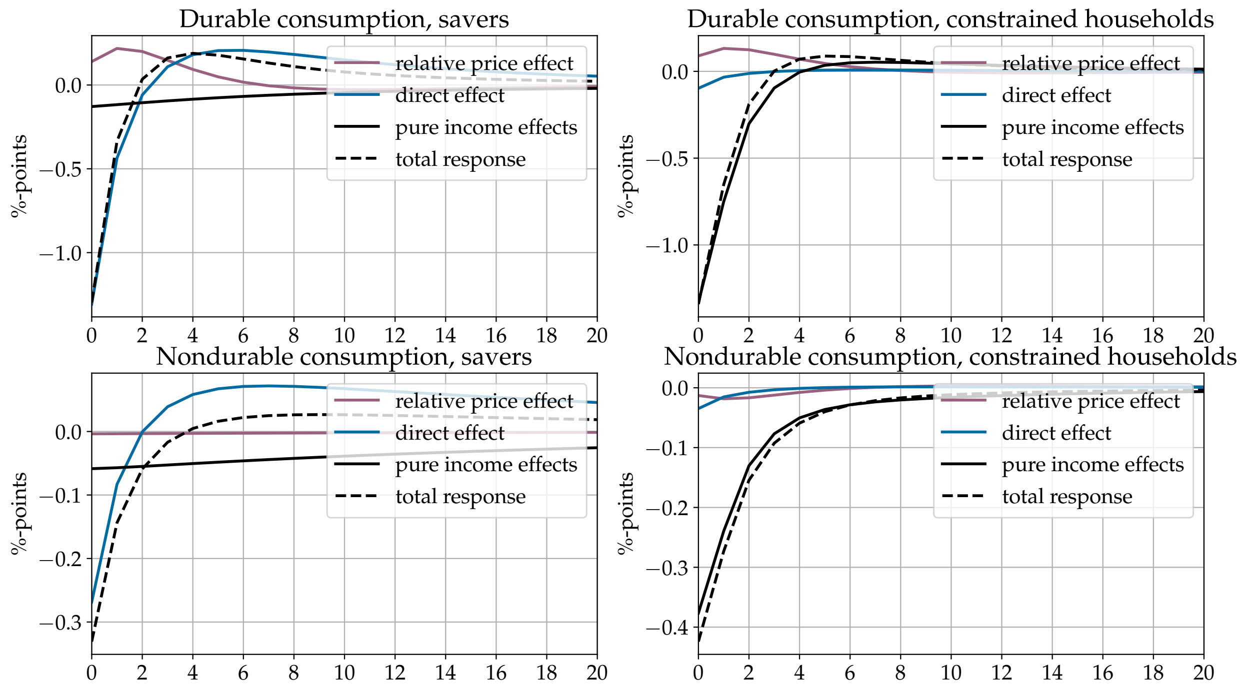
Note: Absolute annual deviations are calculated for visualization purposes.

Figure 10: Detailed consumption response decomposition with sticky wages



Note: Absolute annual deviations are calculated for visualization purposes.

Figure 11: Consumption response decomposition by steady-state wealth percentiles in the model with sticky wages



Note: Model with sticky wages. We document the decomposition of nondurable and durable consumption responses into direct, relative-price and pure income effects, for households differing with respect to their holdings of liquid assets. Liquidity-constrained households are defined as households at the bottom 50% steady-state bond holdings. Savers are defined as households at the steady-state top 1% bond holdings. The effects are calculated using the (initially) truncated distributions relative to a simulation of the relevant truncated distribution conditional on all input variables being at their steady-state values. We consider a 0.25% monetary-policy innovation occurring at $t = 0$.

G Model with sticky wages

We replace the wage schedule equation, (4), with a wage Phillips curve, in the vein of Erceg et al. (2000), Erceg and Levin (2006) and Hagedorn et al. (2019). Specifically, each household provides differentiated labor services, which are transformed into aggregate effective labor, N_t, by perfectly competitive labor packers, using the technology

$$N_t = \left(\int_0^1 \exp\{e(s)_t\} \left(\mathcal{N}(s)_t\right)^{\frac{\epsilon_w - 1}{\epsilon_w}} ds \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} . \tag{66}$$

A union sells labor services at the nominal wage W_t (equalized across production sectors) to the labor recruiter, who minimizes costs given the aggregate demand for labor, implying

$$\mathcal{N}(s)_t = \mathcal{N}\left(W(s)_t; W_t, N_t\right) = \left(\frac{W(s)_t}{W_t}\right)^{-\epsilon_w} N_t \tag{67}$$

for the sth household, and where the equilibrium nominal wage amounts to

$$W_t = \left(\int_0^1 \exp\{e(s)_t\} W(s)_t^{1-\epsilon_w} ds\right)^{\frac{1}{1-\epsilon_w}}. \tag{68}$$

The union sets the nominal wage for one effective labor unit, $\hat{W}_t$, such that $\hat{W}_t = W_t$ subject to virtual Rotemberg adjustment costs:

$$\mathcal{C}_w(\cdot) = \exp\left\{e(s)_t\right\} \frac{\xi_w}{2}\left(\frac{W_{it}}{W_{it-1}} - 1\right)^2 N_t, \tag{69}$$

assuming steady-state $\Pi_w = 1$. The union's wage-setting problem maximizes

$$V_t^w\left(\hat{W}_{t-1}\right) \equiv \max_{\hat{W}_t} \int \frac{\exp\left\{e(s)_t\right\}(1-\tau_t)\hat{W}_t}{P_{n,t}} \mathcal{N}\left(\hat{W}_t; W_t, N_t\right) - \frac{v\left(\mathcal{N}\left(\hat{W}_t; W_t, N_t\right)\right)}{U'_{C_n}\left(C_{n,t}, D_t\right)}\Bigg) ds$$
$$- \int \exp\left\{e(s)_t\right\} \frac{\xi_w}{2}\left(\frac{\hat{W}_t}{\hat{W}_{t-1}} - 1\right)^2 N_t ds + \beta V_{t+1}^w\left(\hat{W}_t\right).$$

This problem yields a wage Phillips curve:[13]

$$(1-\epsilon_w) w_{n,t} + \epsilon_w \frac{U'_{\mathcal{N}}(N_t)}{U'_{C_n}(C_{n,t}, D_t)} - \xi_w\left(\Pi_{w,t} - 1\right)\Pi_{w,t} + \beta\xi_w\left(\Pi_{w,t+1} - 1\right)\Pi_{w,t+1}\frac{N_{t+1}}{N_t} = 0, \tag{70}$$

where the aggregation assumptions are as in Hagedorn et al. (2019), so that one obtains the RA outcome as heterogeneity is turned off.

The steady state is solved as described in Appendix B: however, instead of varying ψ_N such that the wage schedule (4) holds in the steady state, we vary it to ensure that the

[13] See Hagedorn et al. (2019).

steady-state wage Phillips curve holds. As for the dynamic solution, we refer the reader to Appendix E.