Doves for the Rich, Hawks for the Poor? Distributional Consequences of Monetary Policy*

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Abstract

We build a New Keynesian model with rich household heterogeneity. In the model, the systematic response of monetary policy to unemployment and inflation affects both the demand and the supply of financial assets: the demand, because matching frictions render idiosyncratic labor-market risk endogenous; the supply, because firms' markups and capital stock are endogenous to monetary policy. Therefore, accounting for transition dynamics is essential and, as a result, disagreement about systematic monetary stabilization policy is pronounced. The wealth rich or retired favor a monetary policy focused on inflation stabilization. The wealth-poor working class, instead, prefer policy targeted at unemployment stabilization.

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1 Introduction

There is a consensus that modern central banking should rely on a clear inflation objective and the systematic conduct of monetary policy. Taking this as given, however, much less political consensus appears to exist with regard to how, over the business cycle, central banks should weight employment-stability and price-stability objectives. The current paper provides one rationale for the disagreement about optimal monetary policy: it shows that the choice of how to weight inflation stability and employment stability in the systematic conduct of monetary policy can have quantitatively important *distributional* consequences.

We build a heterogeneous-agent New Keynesian business-cycle model ("HANK," in short) with rich household heterogeneity. The model is calibrated so as to match key features of the U.S. wealth and income distribution, tax and welfare system, age structure, and the business cycle. In the model, household disagreement about monetary policy can be traced back both to how large the share of income is that a household draws from working and to households' net worth. The exposure to labor income matters because an inflation-centric monetary policy tends to tolerate larger fluctuations in unemployment, which induce higher unemployment risk and lower lifetime earnings. Households' net worth matters because monetary policy has a permanent effect on the valuation of assets and their payouts. Namely, the conduct of monetary policy affects firms' average markups and, through the interplay of the economy's supply of financial assets and households' demand for savings, the average real interest rate and the capital stock.

The paper has three quantitative findings. First, there is a notable gradient of policy preferences by household net worth and age. Net-worth-rich households (for which labor income finances only a small part of lifetime consumption) and retirees (who tend to have assets and do not earn labor income) favor an inflation-centric policy. Poorer or younger households, instead, favor notably more unemployment stabilization. Nominal redistribution does not play a role in this. The results emerge with real assets only and for a given average inflation rate. Second, for the individual household, the choice of systematic monetary stabilization policy can have welfare consequences that are an order of magnitude larger (in consumption-equivalent terms) than a representative-household view would suggest. Third, a representative household setting ("RANK," henceforth) would also miss the quantitatively important implications for the real rate and the capital stock that a change in systematic monetary policy has in the HANK economy.

The core of the HANK model is standard: nominal rigidities, search and matching frictions in the labor market, and incomplete financial markets. Building on Bewley-Imrohoroglu-Huggett-Aiyagari, we find that the interplay of the demand for savings and the economy-wide supply of financial assets is a central mechanism that shapes the distributional impact of monetary policy. In the model, working-age households save so as to insure against unemployment risk. That risk is caused by search and matching frictions in the labor market (as in Krusell et al. 2010 and Christiano et al. 2016), and it is exacerbated by the risk of persistent earnings losses upon job loss (following Couch and Placzek 2010, Altonji et al. 2013). Differences in educational attainment imply different exposures to unemployment risk (Cairó and Cajner 2018). Next, households save for retirement, so as to supplement social security income and leave bequests (De Nardi 2004). Idiosyncratic labor productivity shocks (including temporary transitions to very high income as in Castañeda et al. 2003) and differences in patience (as in Krusell and Smith 1998, Carroll et al. 2017) allow us to match the wealth distribution in detail. In order to solve the HANK economy, we extend the first-order perturbation-based solution methods developed by Reiter (2009) to second order. While this is computationally costly, it allows us to compute the welfare implications of systematic monetary policy. In addition, building on Andreasen et al. (2018), with this approach we can compute the transition toward the ergodic distribution that is induced by the change in policy.

The policy experiments are as follows. Starting at the average state of the economy that emerges under an empirical baseline policy rule, namely, Taylor (1993), we look at a permanent change to the monetary policy rule. The change can be either toward a more inflation-centric monetary policy, putting a larger weight on the response to inflation, or toward a more unemployment-centric policy, putting a larger weight on unemployment stabilization, or a mix of both. Price-markup shocks mean that there is a tradeoff between stabilizing unemployment and inflation. Household heterogeneity at the time of the policy change means that different groups of households may prefer different characteristics of the systematic conduct of monetary policy.

The disagreement about policy arises because systematic monetary stabilization policy shapes the risks that households face and because systematic monetary stabilization policy affects the level and distribution of average incomes in the economy. Using the calibrated model, the policy preferred by richer or older households means that the standard deviation of the unemployment rate is six times as large as that under the policy preferred by the poor (1.6 percentage points versus 0.25 percentage point). This increase in income risk alone would suggest that the *demand for financial assets* rises, that real interest rates decline, and that capital is crowded in.[1] Instead, our results indicate the opposite: in the HANK economy, upon a change toward an inflation-centric policy, the aggregate capital stock falls *strongly*. We trace this to two sources. First, bigger unemployment fluctuations translate into higher average unemployment (an effect emphasized by Hairault et al., 2010, and Jung and Kuester, 2011). This reduces the marginal product of capital, an effect that prevails even absent heterogeneity. In a model with heterogeneity, the resulting fall in average incomes also dampens households' demand for savings. Second, firms' behavioral response affects the supply of financial assets. Price setters face nominal rigidities and shocks to price markups. An inflation-centric monetary policy means that aggregate demand and marginal costs both tend to be high precisely when markups are low. In the model, therefore, a change toward inflation-centric monetary stabilization policy leads firms to raise average markups. This endogenous movement in markups increases the market value of financial assets: the effective supply of means of saving rises. To induce households to hold the additional supply of financial assets, in equilibrium the real rate of return needs to increase. This, in turn, crowds out capital accumulation. The windfall gains to owners of financial assets explain why high-net-worth working-age households and the retired prefer an inflation-centric policy.

The rest of the paper is organized as follows. Next, we review the literature. Section 2 introduces the model. Section 3 highlights the calibration. Section 4 discusses what type of monetary policy different types of households prefer. The same section documents how

[1] That a change in business-cycle risk can affect the aggregate capital stock and welfare through the demand for savings in heterogeneous agent models is discussed, for example, in Krusell et al. (2009). Our paper links this channel to monetary policy.

these different assessments are shaped by the long-term effects of systematic monetary policy, effects that RANK/or two-agent "TANK" variants would miss. A final section concludes. An extensive (online) appendix provides further details.

Relationship to the literature

A growing literature is concerned with optimal monetary policy in HANK-type incomplete-market settings. Acharya et al. (2020) study utilitarian Ramsey-optimal monetary policy in a model with idiosyncratic income risk and self-insurance against that risk. The authors emphasize that monetary policy shapes both the income risk and the pass-through of income risk to consumption risk, and that (with short-term nominal bonds) the monetary response can redistribute wealth from savers to borrowers. If income risk is countercyclical, all of these factors point toward more accommodative monetary policy than a representative-household model suggests. Similarly, Bhandari et al. (forthcoming) show the Ramsey-optimal monetary response to positive price markup shocks. In their setting, these shocks increase dividends at the expense of labor earnings. If monetary policy is accommodative in response to the shocks, it provides income insurance, and partly undoes the rise in price markups.

Other papers study optimal Ramsey-monetary policy in HANK models with zero liquidity. In an environment with endogenous unemployment risk, Challe (2020) finds that Ramsey-optimal monetary policy would be more accommodative in recessions than a RANK setting. Berger et al. (2019) consider that layoffs leave permanent scars. In their setting, monetary policy should primarily focus on stabilizing unemployment. In our paper, instead, the scarring effects are transitory, so households may save to buffer the effect on consumption.

Our work differs from all of the above papers. First, the papers above look at optimal policy under the veil of ignorance. Our focus, instead, is precisely on the disagreement that arises from households' heterogeneity at the time a policy is first implemented. Second, in our setting this disagreement primarily arises from the transition dynamics that the policy change sets in train. Studying the Ramsey-optimal response to shocks once the economy has settled in the new ergodic distribution would miss this.

An important set of papers clarifies the transmission of monetary and other shocks in HANK models. The mechanisms stressed there apply to our economy, too. Ravn and Sterk (forthcoming) emphasize that countercyclical income risk deepens recessions if monetary policy does not account for the larger fall in the natural rate of interest. Bilbiie (2020) shows that if the income of households with a high marginal propensity to consume is procyclical, this provides further amplification. Broer et al. (2019) emphasize the role of profits or–more generally, the distribution of income–in monetary transmission. Kaplan et al. (2018) highlight the importance of disposable income as opposed to intertemporal substitution. They and Hagedorn et al. (2019) discuss the role of fiscal policy, in particular.

Further important papers within the larger nexus of understanding stabilization policy in HANK frameworks are McKay and Reis (2016), Oh and Reis (2012), Auclert (2019), Bayer et al. (2019), McKay et al. (2016), and Guerrieri and Lorenzoni (2017), who study the role of automatic stabilizers, redistribution, idiosyncratic uncertainty, and forward guidance. Debortoli and Galí (2017) and Bayer et al. (2020) show in, respectively, a calibrated and an estimated model that two-agent, Campbell and Mankiw-type "TANK" economies approximate the cyclical implications of a HANK setting well, as is true in our case. We highlight that, nevertheless, the normative and long-term effects of a change in policy differ starkly between RANK/TANK and HANK.

In terms of policy implications, our paper stands on the shoulders of research that emphasizes the inflation-unemployment trade-off in the New Keynesian model with search and matching frictions, and representative households, such as Faia (2009), Blanchard and Galí (2010), and Ravenna and Walsh (2011). We follow Christiano et al. (2016) in making costs upon hiring the main cost of recruiting. This provides a realistic nexus between inflation and the labor market. Sala et al. (2008) present an estimated New Keynesian model with search and matching frictions. They find that most of the inflation-unemployment stabilization trade-off arises from markup shocks, as is the case in our calibration.

2 Model

There is a unit mass of infinitely lived households. Households receive labor income, social security transfers, and financial income. Idiosyncratic employment risk fluctuates due to Mortensen and Pissarides (1994) search and matching frictions. The prices of goods are sticky. The central bank can, therefore, influence real activity and the distribution of employment risk over the business cycle. Households save to self-insure against idiosyncratic and aggregate risk, and they save for retirement.

2.1 States

The model is defined in recursive form. The economy inherits from the previous period the aggregate capital stock, K_{-1}, and last period's level of wages, investment, and the central bank's policy rate, w_{-1}, i_{-1}, R_{-1}. Next, the economy inherits the type distribution of households from the previous period, μ_{-1}. Let ζ be the vector of aggregate shocks.

For the decisions of firms and households during the period, the notation entertains two different state vectors. A tilde marks the time after aggregate shocks have been realized, but before employment-related transitions (separations, hiring, and earnings losses) have occurred. Let $\widetilde{X} = (K_{-1}, w_{-1}, i_{-1}, R_{-1}, \zeta, \widetilde{\mu})$ denote the state of the economy at that time. $X = (K_{-1}, w_{-1}, i_{-1}, R_{-1}, \zeta, \mu)$, in turn, marks the state of the economy once employment-related transitions have occurred. This is the state of the economy on which production and consumption decisions are based.

2.1.1 Shocks

We look at the distributional consequences of systematic monetary stabilization policy. This means that we need to capture salient features of the business cycle in the first place. We allow for five aggregate shocks, which seem to form the core set of shocks in the literature, collected in vector $\zeta := (\zeta_I, \zeta_R, \zeta_{TFP}, \zeta_w, \zeta_P)$. ζ_I is a shock to the marginal efficiency of investment and ζ_R a monetary policy (interest-rate) shock. ζ_{TFP} is a productivity shock, ζ_w a wage markup shock, and ζ_P a price markup shock.[2] Each shock follows an AR(1)-process with normally distributed innovation

$$\log(\zeta_j{}'/\overline{\zeta}_j) = \rho_{\zeta_j} \log(\zeta_j/\overline{\zeta}_j) + \epsilon'_{\zeta_j},\ \epsilon_{\zeta_j} \overset{\text{iid}}{\sim} N(0, \sigma^2_{\zeta_j}), \rho_{\zeta_j} \in [0,1), \sigma_{\zeta_j} \geq 0.$$

[2]Christiano et al. (2016) identify the first three shocks and find that they are important. Smets and Wouters (2007), in addition, identify a "wage-markup" shock and a "price-markup" shock as important.

Here and in the following, a bar over a variable refers to the variable's value in the deterministic steady state, and a prime marks the next period.

2.1.2 Individual states

Household heterogeneity can be summarized by six idiosyncratic states (n, a, l, e, b, s). The first three (n, a, l) are affected by the business cycle, and so are endogenous to monetary policy. The last three (e, b, s) evolve exogenously. $n \in \{0, 1\}$ denotes the household's employment state, $a \in \mathbb{R}_+$ marks the household's holdings of shares of a representative mutual fund, and $l \in \{0, 1\}$ the household's earnings-loss state. $e \in \{e_L, e_H\}$ marks the household's education level (high or low). $b \in \{0, 1\}$ marks the household's impatience. $s \in \mathcal{S}$ marks an exogenous component of a household's current labor productivity ("skills"). Labor productivity s follows a first-order Markov process with $s \in \mathcal{S} = \{s_0, s_1, s_2, s_3\}$. $\pi_S(s, \hat{s})$ denotes the probability of a transition from s to $\hat{s}$. Skill state $s_0 = 0$ is associated with retirement: the household does not work but receives retirement benefits. If $s \in \mathcal{S}_+ := \mathcal{S} \setminus s_0$, the household is in the labor force and s captures differences in productivity after conditioning on education and the household's employment history. The household draws a fresh s at the beginning of every period. The probability of retiring is the same for each skill state $s \in \mathcal{S}_+$, so that $\pi_S(s, s_0) = \pi_{s_0}$ for each $s \in \mathcal{S}_+$. Each period, a retired household returns to the labor force (is "born") with probability $\pi_S(s_0, \hat{s})$, $\hat{s} \in S_+$.

At the beginning of a household's working life (that is, when a household transitions from $s = s_0$ to $s \in \mathcal{S}_+$), a household draws its education level and time preferences, and only then. $\pi_E(e, \hat{e})$ marks the probability of moving from education level e to education level $\hat{e}$. $\pi_b(b)$ marks the probability of drawing impatience state b, with $b \in \{0, 1\}$. The household's time preference is given by $\beta(e, b) = \beta_e - \Delta_\beta b$ (with $\beta_e \in \{\beta_{e_L}, \beta_{e_H}\}$ and $\Delta_\beta \geq 0$). Time discount factors depend on education. We use this to match the wealth distribution by education. Heterogeneity in discount factors within an education group is used to match the low net worth of the poor.

It remains to specify the evolution of the endogenous individual states (n, a, l). Share holdings a are determined by the savings behavior of the household. For households in the labor force, the evolution of the employment state n is governed by the search and matching structure of the model. l captures an earnings loss. When the household is employed, its idiosyncratic productivity is given by the product $e \cdot s \cdot (1 - \varrho l)$. Parameter ϱ in $[0, 1)$ measures the size of the earnings loss ($l = 1$). The earnings-loss state evolves with the household's employment history. $\pi_L^{uem}(1)$ is the probability of suffering an earnings loss when moving from unemployment to employment. $\pi_L^{emp}(l, \hat{l})$ is the probability of the earnings-loss state changing from l to $\hat{l}$ if the household enters the period employed. Households change their earnings-loss state after employment transitions have occurred.

The mass of households that are born, by construction, equals that of retiring households. After having drawn the education state, the newborn household draws states n and l such that the mass of households of type (n, l, e) is not affected by transitions to and from retirement.

Let $\mu(n, a, l, e, b, s)$ mark the type distribution of households after all idiosyncratic transitions of the period have occurred. μ has support on $\mathcal{M} := \{0, 1\} \times [0, 1] \times \{0, 1\} \times \{e_L, e_H\} \times \{0, 1\} \times \mathcal{S}$.[3]

2.1.3 Employment transitions

The data support the notion that job-finding rates $f(\widetilde{X})$ are the same for all unemployed households. Flow rates into unemployment, instead, depend on education. Hiring decisions in the model will be made by firms. The common-to-all job-finding rate, $f(X)$, will fluctuate over the business cycle. Let $\lambda(e)$ be the (constant) probability that a firm and household separate. We split this rate in two: $\lambda(e) = \lambda_x(e) + \lambda_n(e)$. At rate $\lambda_x(e)$, households flow directly into the unemployment pool for the period (exit employment). At rate $\lambda_n(e)$, households separate from a firm and search for a job in the same period (subscript n to mark the option of employment). If successful, the household will return to employment in the same period. Otherwise, the household will be unemployed. The flow rates into unemployment, thus, are cyclical. They are allowed to depend on educational attainment.

[3]Only some combinations of idiosyncratic states are admissible. We consider all retired households ($s = s_0$) as unemployed ($n = 0$). Only the employed ($n = 1$) can be subject to skill loss ($l = 1$).

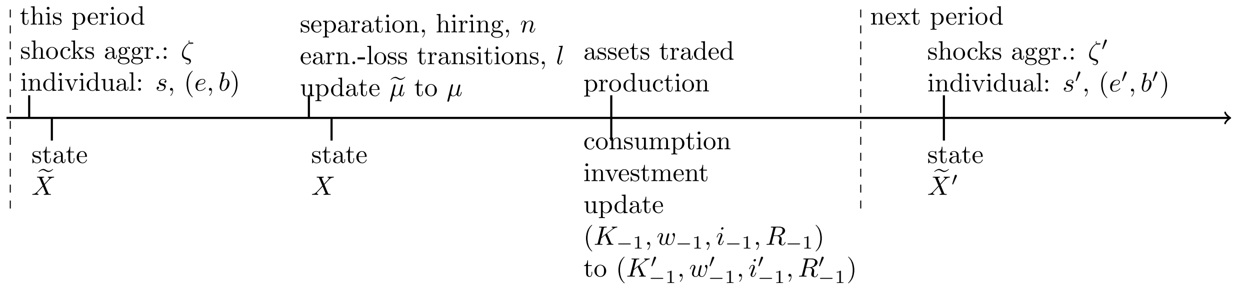


Figure 1: Timing of decisions

2.2 Timing

The timing is shown in Figure 1. At the beginning of each period, households draw new skills s. If a household is born (a transition from s_0 to $s \in \mathcal{S}_+$), the household draws an education level from $\pi_E(e, e')$ and time preferences $b \in \{0, 1\}$. A household that is born is randomly assigned to states n and l in such a way that it replaces a retiring household with these employment and earnings-loss characteristics and the same education level. Aggregate shocks are drawn. The tilde marks the time at the beginning of the period after all those shocks have been realized, but before employment transitions (separations and hiring) have occurred. Denote by $\widetilde{\mu}$ the corresponding type distribution at that point in time. Let $\widetilde{X} = (K_{-1}, w_{-1}, i_{-1}, R_{-1}, \zeta, \widetilde{\mu})$ denote the corresponding state of the economy. Before production takes place, firms separate from a household of education e with probability $\lambda_x(e) + \lambda_n(e)$. Thereafter, the employed with earnings losses shed those with probability $\pi_L^{emp}(1, 0)$. Then, firms post vacancies. A share $\lambda_n(e)/(\lambda_x(e) + \lambda_n(e))$ of the separated households of education level e search for a new job in the same period, as do the unemployed. All other separations flow directly into the unemployment pool for the period. Matching takes place. Households hired out of unemployment face the earnings-loss probability $\pi_L^{uem}(1)$. Accounting for the employment transitions, and subsequent transitions in the earnings-loss state, the aggregate state becomes $X = (K_{-1}, w_{-1}, i_{-1}, R_{-1}, \zeta, \mu)$, where μ marks the type distribution at the time of production. Then the remaining decisions are made and firms produce.

2.3 Households' problems

Household preferences are time-separable with education- and shock-dependent time discount factor $\beta(e, b) \in (0, 1)$. Households derive utility from consumption, c. Period felicity is given by $u(c) = c^{1-\sigma}/(1-\sigma), \sigma > 0$. In addition, retired households derive utility from leaving bequests to the newborn upon "death." The utility from leaving a bequest of a shares worth $p_a(X)a$, conditional on death, is $\gamma_1 \cdot (p_a(X)a + \gamma_2)^{1-\sigma}/(1-\sigma)$, where $\gamma_1, \gamma_2 \geq 0$. The approach and functional form for this warm-glow utility of bequest follow De Nardi (2004).[4] Government consumption enters household preferences in an additively separable way. Since it is held constant throughout the paper, we do not model this part of preferences. We first describe the problem of a household that is employed after the employment transitions have taken place. Thereafter, we describe the problem of an unemployed household. Last, we describe the problem of a household that is retired.

2.3.1 Employed households

Let $W(X, n, a, l, e, b, s)$ be the value of a household at the time of production. The employed household's Bellman equation ($n = 1$, $s \in \mathcal{S}_+$) is given by

$$
\begin{aligned}
W(X,1,a,l,e,b,s) = \max_{c,a'\geq 0} \Big\{ \quad & u(c) + \pi_{s_0}\mathbb{E}_\zeta\left[\beta(e,b)W(X',0,a',0,e,b,s_0)\right] \\
& + \textstyle\sum_{s'\in\mathcal{S}_+} \pi_S(s,s')\beta(e,b)\cdot \\
& \mathbb{E}_\zeta\Big[\quad [1-\lambda_x(e)-\lambda_n(e)(1-f(\widetilde{X}'))] \textstyle\sum_{\hat{l}} \pi_L^{emp}(l,\hat{l}) W(X',1,a',\hat{l},e,b,s') \\
& + [\lambda_x(e)+\lambda_n(e)\big(1-f(\widetilde{X}')\big)]W(X',0,a',0,e,b,s') \ \Big] \quad \Big\}
\end{aligned}
$$

$$
\begin{aligned}
\text{s.t.} \quad (1+\tau_c)c + p_a(X)a' = \quad & [p_a(X)+d_a(X)]\,a \\
& + w(X)es(1-l\varrho)\,[1-\tau_{RET}-\tau_{UI}-\tau(X,w(X)es(1-l\varrho)]
\end{aligned}
$$

The household chooses consumption and non-negative share holdings. On the right-hand side of the Bellman equation appear period felicity and the continuation values. Next period, the household will enter retirement with probability π_{s_0}, carrying with it its asset holdings and education status, the household's value being $W(X',0,a',0,e,b,s_0)$.[5] Otherwise, the household will remain in the labor force at newly drawn skill state s'. The expectation operator $\mathbb{E}_\zeta$ marks expectations formed with regard to aggregate shocks. Conditional on not retiring next period, with probability $1-\lambda_x(e)-\lambda_n(e)(1-f(\widetilde{X}'))$, the household will remain

[4] γ_1 can be thought of as controlling the strength of the bequest motive, while γ_2 determines how much of a luxury good leaving a bequest is.

[5] The notation moves all households that enter retirement or unemployment to the no-earnings-loss state $l = 0$.

employed. The household draws a new idiosyncratic earnings-loss state $\hat{l}$, with $\pi_L^{emp}(l,\hat{l})$ marking the transition probability of the earnings-loss state for an employed household. The household's value then is $W(X',1,a',\hat{l},e,b,s')$. Otherwise, the household will move into unemployment, with the associated value being $W(X',0,a',0,e,b,s')$.

As per the budget constraint, the household buys consumption goods, c, pays consumption tax τ_c, and purchases shares at cost $p_a(X)a'$. On the income side, the household has the cum-dividend value of shares brought into the period and labor earnings, $w(X)es(1-l\varrho)$. $w(X)$ is the real wage per efficiency unit of labor and $\varrho \in [0,1)$ is the loss of earnings associated with the earnings-loss state. Three types of taxes are applied to earnings: social security taxes, τ_{RET}, unemployment-insurance taxes, τ_{UI}, and labor-income taxes, $\tau(X,.)$.

2.3.2 Unemployed households

The unemployed household's Bellman equation ($n=0$, $s \in \mathcal{S}_+$) is given by

$$\begin{aligned} W(X,0,a,0,e,b,s) = \quad & \max_{c,a'\geq 0} \Big\{ u(c) + \pi_{s_0}\,\mathbb{E}_\zeta[\beta(e,b)W(X',0,a',0,e,b,s_0)] \\ & + \textstyle\sum_{s'\in\mathcal{S}_+} \pi_S(s,s')\beta(e,b)\mathbb{E}_\zeta\Big[f(\widetilde{X}')[\quad \pi_L^{uem}(1)W(X',1,a',1,e,b,s') \\ & + \pi_L^{uem}(0)W(X',1,a',0,e,b,s')] + \big(1-f(\widetilde{X}')\big)W(X',0,a',0,e,b,s')\Big]\Big\} \end{aligned}$$

$$\text{s.t.} \quad (1+\tau_c)c + p_a(X)a' = \quad [p_a(X)+d_a(X)]\,a + b_{UI}(es)[1-\tau(X,b_{UI}(es))].$$

With probability π_{s_0}, the household moves into retirement. Otherwise, next period, the household will move into employment with state-dependent probability $f(\widetilde{X}')$. Upon reemployment, with probability $\pi_L^{uem}(1)$, the household will suffer an earnings loss, or else no earnings loss. If the household does not find a new job, it will stay unemployed next period. As per the budget constraint, instead of labor earnings the unemployed household receives unemployment benefits, $b_{UI}(es)$. They are assumed to depend on the household's earnings capacity. This is meant to capture, in a parsimonious way, the fact that benefits depend on past earnings.

2.3.3 Retired households

The retired household's Bellman equation ($s = s_0$) is given by

$$\begin{aligned} W(X,0,a,0,e,b,s_0) = \quad & \max_{c,a'\geq 0} \Big\{ u(c) + \pi_S(s_0,s_0)\beta(e,b)\mathbb{E}_\zeta \left[W(X',0,a',0,e,b,s_0)\right] \\ & +(1-\pi_S(s_0,s_0))\mathbb{E}_\zeta \left[\gamma_1 \tfrac{(p_a(X')a+\gamma_2)^{1-\sigma}}{1-\sigma}\right] + \hat{W}(X',0,a',0,e,b,s_0)\Big\} \\ \text{s.t.} \quad (1+\tau_c)c + p_a(X)a' = \quad & \left[p_a(X) + d_a(X)\right] a + b_{RET}(e)[1-\tau(X, b_{RET}(e))]. \end{aligned}$$

The first row describes the flow utility from consumption this period and the continuation value of remaining retired with probability $\pi_S(s_0, s_0)$. The following row concerns a household that is re-born (joins the labor force out of retirement). Upon "death," the retired household receives utility from leaving a bequest (first term on second row). In addition, the household receives a value $\hat{W}(X', 0, a', 0, e, b, s_0)$ that describes the expected continuation value at re-birth. $\hat{W}$ is a longer expression and is spelled out in Appendix A.1. It reflects the assumption that the newly born household draws new idiosyncratic skills, s, and also redraws the education level. In terms of employment and earnings-loss status (n, l), we assume that the newborn household randomly replaces a retiring household. The budget constraint of the retired (third row) is the same as for the unemployed, but features retirement benefits $b_{RET}(e)$ instead of unemployment benefit payments.

2.4 Production

Production of the final good, used for consumption and investment, is performed in stages by four different types of firms, which we will describe in detail below. There is a representative final goods firm that assembles this good from differentiated varieties of intermediate goods. Intermediate goods producers are subject to nominal rigidities. They themselves demand homogeneous labor services and capital services from firms specializing in the production of these services.[6] All firms in the economy are owned by households through their ownership

[6]We decentralize the production side into different firms for ease of presentation. Assuming that the intermediate good producers own capital and hire workers directly leads to identical aggregate quantities and prices; see the working-paper version, Gornemann et al. (2021), for details.

of shares in mutual funds. All profits, thus, flow to households in the form of dividends. Dividends are taxed at a fixed rate τ_d.

2.4.1 Final goods production

There is a representative final goods firm. The firm assembles differentiated goods, the latter indexed by $j \in [0,1]$, into a homogeneous final good. Let $X_p := (X, \eta_p)$ be state X augmented by the distribution η_p of last period's prices.[7] The final goods firm solves

$$\max_{y,(y_j)_{j\in[0,1]}} \quad (1-\tau_d)\left(P(X_p)y - \int_0^1 P_j(X_p)y_j dj\right) \quad \text{s.t. } y = \left(\int_0^1 y_j^{\frac{\vartheta\cdot\exp\{\zeta_P\}-1}{\vartheta\cdot\exp\{\zeta_P\}}} dj\right)^{\frac{\vartheta\cdot\exp\{\zeta_P\}}{\vartheta\cdot\exp\{\zeta_P\}-1}}.$$

$P(X_p)$ is the aggregate price level. y marks output of final goods. $P_j(X_p)$ marks the price of differentiated good j. y_j marks the demand for that good. Parameter $\vartheta > 1$ marks the long-run elasticity of demand. ζ_P is a shock that results in fluctuations of price-setting firms' markups (a "price-markup shock").

2.4.2 Production of intermediate inputs

Varieties of the intermediate good serve as inputs into final-good production. Homogeneous labor services and capital services, in turn, serve as inputs into the production of differentiated goods. We describe the related firms' problems next.

Intermediate goods producers. There is a unit mass of producers of intermediate goods. Producers face Rotemberg (1982) quadratic price adjustment costs and sell in monopolistically competitive markets. The producer of variety j (after taxes) has the value

$$\begin{aligned} J_D(X_p;j) = \max_{P_j,\ell_j,k_j} \quad (1-\tau_d)\Bigg(& y_j(X,P_j,P(X_p))\left(\frac{P_j}{P(X_p)}\right) - r(X)k_j - h(X)\ell_j - \Xi \\ & -\frac{\psi}{2}\left(\frac{P_j}{P_{j,-1}} - \overline{\Pi}\right)^2 y(X)\Bigg) + \mathbb{E}_\zeta\left[Q(X,X')J_D(X_p';j)\right] \end{aligned}$$

[7] In equilibrium, all differentiated goods producers will set the same price. Therefore, in equilibrium, X describes the state of the economy. Anticipating this, in much of the exposition we use X to index the state of the economy, rather than X_p. We use X_p whenever necessary for clarity.

$$\text{s.t.} \qquad y_j(X, P_j, P(X_p)) = \zeta_{TFP} k_j^{\theta} \ell_j^{1-\theta}, \tag{1}$$

$$y_j(X, P_j, P(X_p)) = \left(\frac{P_j(X_p)}{P(X_p)}\right)^{-\vartheta \cdot \exp\{\zeta_P\}} y(X). \tag{2}$$

After setting its price P_j, producer j faces demand $y_j(X, P_j, P(X_p))$. In order to meet the demand, the producer rents capital and labor services k_j and ℓ_j at the competitive rates $r(X)$ and $h(X)$ (first line). $\Xi > 0$ is a fixed cost of production. Price adjustment is costly (second line). $\overline{\Pi}$ marks the steady-state gross inflation rate. Parameter $\psi > 0$ indexes the extent of price adjustment costs. The final term on the second row is the differentiated goods producer's continuation value. It discounts the future using discount factor $Q(X, X')$, which is the discount factor employed by the mutual funds (see Section 2.5 below). Equation (1) is the production function, with $\theta \in (0, 1)$ and ζ_{TFP} the productivity shock. Equation (2) is the demand function.

Labor services. Labor services are homogeneous. They are intermediated by employment agencies, which operate under constant returns to scale. Employment agencies recruit a worker/household through random search. The value of a household to an employment agency depends on the household's characteristics (l, e, s). This value is given by

$$\begin{aligned} J_L(X, l, e, s) \quad = \quad & (1 - \tau_d)[h(X) - w(X)] \cdot es(1 - \varrho l) + \textstyle\sum_{s' \in \mathcal{S}_+} \pi_S(s, s' | s' \neq s_0) \cdot \\ & \big(1 - \lambda_x(e) - \lambda_n(e)\big) \mathbb{E}_\zeta \big[Q(X, X') \textstyle\sum_{l'} \pi_L^{emp}(l, l') J_L(X', l', e, s')\big]. \end{aligned}$$

A household with characteristics l, e, s produces $es(1 - \varrho l)$ units of labor services, which the agency sells at competitive price $h(X)$. Per efficiency unit of labor, the agency pays a real wage of $w(X)$ (first terms). The household's transitions affect its value to the employment agency. The household may separate from the agency with probability $1 - \lambda_x(e) - \lambda_n(e)$. Otherwise, the household provides value $J_L(X', l', e, s')$ to the agency next period, after transitions in skills to s' and the earnings-loss state to l' are accounted for.[8]

After separations have occurred, and before production, employment agencies can recruit. Let $V(\widetilde{X})$ be the aggregate number of vacancies posted and $M(\widetilde{X}, V)$ the aggregate mass

[8] Without loss, here we assume that a household that moves into retirement will immediately be replaced by a "newborn" household of the same payoff-relevant characteristics.

of new matches. The free-entry condition for recruiting is given by

$$\begin{aligned}&\textstyle\sum_{e,s\in\mathcal{S}_+}\pi_S(s|s\in S_+)\frac{U(\widetilde{X},e)}{\sum_e[U(\widetilde{X},e)+\lambda_n(e)\sum_l N(\widetilde{X},l,e)]}\sum_{\hat{l}}\pi_L^{uem}(\hat{l})J_L(X,\hat{l},e,s)\\&+\textstyle\sum_{e,l,s\in\mathcal{S}_+}\pi_S(s|s\in S_+)\frac{\lambda_n(e)N(\widetilde{X},l,e)}{\sum_e[U(\widetilde{X},e)+\lambda_n(e)\sum_l N(\widetilde{X},l,e)]}\sum_{\hat{l}}\pi_L^{emp}(l,\hat{l})J_L(X,\hat{l},e,s)\\&\qquad\qquad\qquad=(1-\tau_d)\kappa\left(\frac{M(\widetilde{X},V(\widetilde{X}))/\left(\sum_{l,e}N(\widetilde{X},l,e)\right)}{\overline{M}/\overline{\widetilde{N}}}\right)^2.\end{aligned}$$

In equilibrium, recruiting will occur until the expected gain of a hire (left-hand side) equals the average after-tax cost per hire. The gain is given by the expected value of a household to the employment agency, accounting for the distribution of household characteristics in the pool of households searching for employment, and their subsequent earnings-loss transitions. The pool of searching households is composed of the unemployed (first row) and of newly separated households that look for employment within the same period (second row).

For the costs of recruiting (third row), we assume that firms pay a cost $\kappa > 0$ upon successfully recruiting a worker, based on the evidence in Silva and Toledo (2009) and Christiano et al. (2016).[9] In addition, we follow Gertler and Trigari (2009) and Yashiv (2000), and assume that the costs of hiring are convex (quadratic) in the aggregate hiring rate. Here $\overline{M}$ and $\overline{\widetilde{N}}$ mark the steady-state values of matches and employment.

Matches emerge according to the den Haan et al. (2000) matching function

$$M(\widetilde{X},V(\widetilde{X}))=\frac{\left(\sum_e\left[U(\widetilde{X},e)+\lambda_n(e)\sum_l N(\widetilde{X},l,e)\right]\right)V(\widetilde{X})}{\left(\left(\sum_e\left[U(\widetilde{X},e)+\lambda_n(e)\sum_l N(\widetilde{X},l,e)\right]\right)^{\alpha}+V(\widetilde{X})^{\alpha}\right)^{\frac{1}{\alpha}}},\ \alpha>0.$$

This links the mass of households searching for a job to the mass of vacancies. Households have job-finding rate $f(\widetilde{X}) = M(\widetilde{X}, V(\widetilde{X}))/\left(\sum_e\left[U(\widetilde{X},e)+\lambda_n(e)\sum_l N(\widetilde{X},l,e)\right]\right)$. Firms' job-filling probability is given by $q(\widetilde{X}) = \frac{M(\widetilde{X},V(\widetilde{X}))}{V(\widetilde{X})}$.

A wide range of wages is bilaterally efficient. We postulate that the wage evolves according to a wage rule that allows for wage rigidity. In particular, the wage evolves according to

$$\log(w(X)/\overline{w}) = \phi_w\ \log(w_{-1}(X)/\overline{w}) + (1-\phi_w)\ \log\left(\frac{y(X)}{\overline{y}}\right) + \zeta_w. \tag{3}$$

[9] They point to more than 90 percent of recruitment costs occurring after a candidate has been found.

This rule has the potential to amplify the effect of business-cycle shocks on unemployment and to propagate the shocks over time; see Blanchard and Galí (2010) and the literature overview in Rogerson and Shimer (2011). Above, $\overline{w}$ is the steady-state wage level. Parameter $\phi_w \in [0, 1)$ governs wage rigidities over time, and how much the wage reacts to economic activity. Last, there is the wage-markup shock, ζ_w.

Capital services. There is a representative producer of homogeneous capital services. Capital services are the product of the capital stock, K, and the utilization of capital, v. The value of the capital services producer is

$$\begin{aligned} J_K(X, K_{-1}, i_{-1}) &= \max{}_{v,i,K}(1 - \tau_d)[r(X)K_{-1} \cdot v - i] + \mathbb{E}_\zeta [Q(X, X')J_K(X', K, i)] \\ & \quad \text{s.t.} \qquad K = \left[1 - \delta(v)\right] \cdot K_{-1} + \zeta_I \cdot [1 - \Gamma(i/i_{-1})]i. \end{aligned}$$

As in Greenwood et al. (1988), the more intensively capital is utilized, the more it depreciates: $\delta(v) = \delta_0 + \delta_1 (v^{\delta_2} - 1)$, with $\delta_0, \delta_1 > 0$, and $\delta_2 > 1$. Capital accumulation is subject to investment adjustment costs, as is customary (Christiano et al. 2005). Namely, $\Gamma\left(\frac{i}{i_{-1}}\right) = \phi_K/2 \left(\frac{i}{i_{-1}} - 1\right)^2$, $\phi_K > 0$. ζ_I is the shock to the marginal efficiency of investment.

2.5 Mutual funds

Households own claims to firms' cash flows only indirectly, through holding shares in representative mutual funds. The funds own all of the producers discussed above. Since financial markets are incomplete, there is typically not a unique natural candidate for the stochastic discount factor. Therefore, we need to choose one with which the funds endow the producers. For numerical tractability, we assume that the funds discount the future using

$$Q(X, X') = \frac{p_a(X)}{p_a(X') + d_a(X')}.$$

This discount factor is the inverse of the gross return on shares. The discount factor is admissible in the sense that it is consistent with the share-holding households' Euler equations by construction. Note further that, absent risk or up to the first order, the fund would discount the future at the equilibrium gross real interest rate.[10]

Through the discount factor, producers endogenously respond to the households' demand for savings. For example, an autonomous rise in households' desire to save today would raise the equilibrium price of shares $p_a(X)$, all else equal. The ensuing increase in $Q(X, X')$ would lead producers to value future cash flows more. This would, then, for instance, induce a rise in capital investment, in the same way that the capital stock would rise if households had held the capital stock outright.

The mutual funds distribute to the households all income that is not reinvested, paid to workers, or used for paying fixed costs, hiring costs, or price adjustment cots. After-tax dividends are given by

$$\begin{aligned} d_a(X) \quad = \quad (1-\tau_d) \quad & \Big(y(X) - \Xi - \tfrac{\psi}{2}\left(\Pi(X) - \overline{\Pi}\right)^2 y(X) - \textstyle\int_{\mathcal{M}} w(X) se(1-\varrho l) \mathbb{1}_{n=1}\, d\mu \\ & -i(X) - \kappa \left(\frac{M(\widetilde{X}, V(\widetilde{X}))/\left(\sum_{l,e} N(\widetilde{X}, l, e)\right)}{\overline{M}/\overline{\widetilde{N}}} \right)^2 M(\widetilde{X}, V(\widetilde{X})) \Big), \end{aligned}$$

where $\mathbb{1}$ marks the indicator function, meaning $\mathbb{1}_{n=1}$ marks employment of the household. $\Pi(X)$ denotes the gross inflation rate.

2.6 Central bank and fiscal authority

We use the cashless limit (Woodford, 1998), by which the central bank controls the gross nominal interest rate $R(X)$ on risk-free nominal bonds (which the mutual funds trade among each other). The mutual funds' optimal decisions then yield a standard Euler equation (for the mutual fund rather than a household)

$$1 = \mathbb{E}_\zeta \left[Q(X, X') \frac{R(X)}{\Pi(X')} \right].$$

The central bank sets the gross nominal interest rate according to Taylor rule

$$\log\left(\tfrac{R(X)}{\overline{R}}\right) \quad = \quad \phi_R \log\left(\tfrac{R_{-1}}{\overline{R}}\right) + (1-\phi_R)\left[\phi_\Pi \log\left(\tfrac{\Pi(X)}{\overline{\Pi}}\right) - \phi_u \left(\tfrac{U(X) - \overline{U}}{\pi_S(\mathcal{S}_+)}\right)\right] + \log \zeta_R. \quad (4)$$

[10] Using this (asset-price-based) discount factor in our RANK model, results of which we show as a point of comparison below, leads to virtually the same results as using the RANK model's representative household's discount factor directly.

The first term on the right-hand side reflects interest persistence, with $\phi_R \in [0,1)$ (R_{-1} is the rate set in the previous period). Interest persistence apart, the central bank raises the nominal interest rate above the steady-state level $\overline{R}$ whenever inflation exceeds the inflation target of $\overline{\Pi}$ ($\phi_\Pi > 1$) or the unemployment rate is lower than the steady-state value (parameter $\phi_u \geq 0$).[11]

The fiscal authority adjusts labor taxes, $\tau(X, \cdot)$, so as to balance the budget period by period. Appendix A.3 spells out the government budget constraint. We introduce the functional form for the (progressive) tax function further in Section 3.3 below.

2.7 Market clearing and equilibrium

We state the full definition of equilibrium in Appendix B, including the law of motion for the distribution. Here we only state the market-clearing conditions. Market clearing for final goods requires that all final output be used for personal consumption, investment, government consumption, fixed costs or adjustment costs:

$$\begin{aligned} y(X) \quad = \quad & \int_{\mathcal{M}} c(X,n,a,l,e,s)\ d\mu + i(X) + g + \tfrac{\psi}{2}\left(\Pi(X) - \overline{\Pi}\right)^2 y(X) \\ & + \kappa \left(\frac{M(\widetilde{X}, V(\widetilde{X}))/\left(\sum_{l,e} N(\widetilde{X},l,e)\right)}{\overline{M}/\widetilde{\overline{N}}} \right)^2 M(\widetilde{X}, V(\widetilde{X})) + \Xi. \end{aligned}$$

The market for differentiated goods clears if demand equals production (using symmetry in both price setting and demand for each differentiated good j), so $y(X) = \zeta_{TFP} k_j^\theta \ell_j^{1-\theta}$ with k_j and ℓ_j identical for all $j \in [0,1]$. The market for labor services clears if all labor services supplied are used in the production of differentiated goods, $\int_{\mathcal{M}} se(1-\varrho l)\mathbb{1}_{n=1}\ d\mu = \int_0^1 \ell_j\ dj$, The market for capital services clears if $v(X)K_{-1} = \int_0^1 k_j\ dj$. Normalizing the supply of shares to unity, and marking with $a(X,n,a,l,e,s)$ the savings policies of households, the market for shares in the mutual fund clears if $\int_{\mathcal{M}} a(X,n,a,l,e,s)\ d\mu = 1$. Last, the bond market clears if bonds traded among mutual funds are in zero net supply.

[11] $U(X) := \sum_e U(X,e)$ is the mass of unemployed households and $\pi_S(\mathcal{S}_+)$ is the mass of households that are not retired. Therefore, the term $U(X)/\pi_S(\mathcal{S}_+)$ in the Taylor rule is the unemployment rate.

3 Calibration

We calibrate the model to the U.S. economy, one period being a quarter. The calibration sample is 1984Q1 to 2008Q3. It covers the Great Moderation and stops right before the zero lower bound on nominal interest rates becomes binding. Our solution method relies on second-order perturbation. This allows us to capture the effects that systematic monetary policy has on households' welfare and on long-term outcomes.[12] The solution method is a version of the method developed by Reiter (2009) and Reiter (2010), and is described in detail in Appendix C. We use splines to approximate households' decision rules along their asset dimension and approximate the distribution of households as a histogram on the product of a household's skill, education, and employment, and a grid on the wealth distribution.

In calibrating the model, wherever possible we choose parameters based on direct outside evidence or based on targets for the steady state. Unless mentioned otherwise, these targets are to be met exactly. Next, we discuss the calibrated parameters. We relegate summary tables for all sections to Appendix D.1.

3.1 Preferences, skills, and education

We set the coefficient of relative risk aversion to $\sigma = 2.5$, within the range typically estimated in the micro literature; see, for example, Blundell et al. (2016). We assume that the mass of patient and impatient households is equal, so that $\pi_b(0) = \pi_b(1) = 0.5$.[13] Parameters $\beta_{e_L} = 0.974$, $\beta_{e_H} = 0.985$, $\Delta_\beta = 0.11$, $\gamma_1 = 18,854$, and $\gamma_2 = 6.1$ characterize time and bequest preferences. They emerge jointly from five targets. We target a post-tax real rate of return of 3.05 percent. We also target moments of the wealth distribution: a wealth share for the poorest 20 percent of the working-age population of close to zero; a wealth share of the low-educated of 30 percent; and a wealth share of the poorest 50 percent of the retired of 5.25 percent. Last, we minimize the distance between the wealth Lorenz curve for working-age households in the data and the steady state of the model; all data counterparts

[12] The solution method cannot handle the zero lower bound on the nominal interest rate. This is why our sample ends in 2008Q3.

[13] It is common to assume that heterogeneity in β follows a uniform distribution and then to approximate the distribution with few grid points; see, for example, Krueger et al. (2016) and Carroll et al. (2017).

are taken from the SCF; see Appendix E.1.

Our definition of high education is a college degree. We normalize $e_L = 1$ and fix $e_H = 1.5$ to match the college premium as in Mukoyama and Sahin (2006). The probabilities $\pi_E(e_L, e_L) = 0.8$ and $\pi_E(e_H, e_H) = 0.7$ arise from two targets. First, in the SCF 60 percent of working-age heads of household do not have a college degree. Second, we target an intergenerational elasticity of incomes of 0.5, in the mid-range of what the literature finds; see, for example, Solon (1992) and Mazumder (2005).

In regard to earnings losses, Couch and Placzek (2010) report that earnings losses upon displacement are 30 percent; Altonji et al. (2013) report an initial drop of 20 percent. We set $\varrho = 0.25$ to match the midpoint. Couch and Placzek (2010) report that earnings losses still run at 13-15 percent six years after displacement. We set $\pi_L^{emp}(1, 0) = 0.025$ to match a loss of 14 percent after that time. While employed, households can shed an earnings loss, but cannot acquire one, so $\pi_L^{emp}(0, 1) = 0$. The probability of acquiring an earnings loss upon leaving unemployment is $\pi_L^{uem}(1) = 1 - \pi_L^{emp}(1, 0)$. This ensures that a household is not more likely to shed an earnings loss through a spell of unemployment than in employment. The table in Appendix D.1.1 summarizes the parameter choices discussed above.

Turning to skills, there are four skill states: s_0 marks retirement; the remaining skill levels refer to working age. s_1 marks the lowest skill, s_2 medium skills, and s_3 vastly higher skills as in Castañeda et al. (2003). Skills follow a first-order Markov process. We need to parameterize the level of skills and the transition matrix. We target an average working life of 40 years and an average length of retirement of 12 years. Defining working age as 25-65 years of age, these targets are in line with the SCF. Transitions into retirement are independent of a working-age worker's skill level. Upon entering working age, workers draw a skill level according to the ergodic distribution of skills. In addition, we set targets for the transitions between skill states for working-age households. In calibrating skill state s_3 (the vastly more skilled), we follow Nakajima (2012): that group makes up 1 percent of the working-age population; the probability of remaining in the group (if not retiring) is 0.975, and the probability of drawing skill s_3 is the same whether the current skill state is s_1 or s_2. Next, the probability of moving to the lower-skill states from s_3 is based on the ergodic distribution. The final targets concern skill levels s_1 and s_2. We assume that low- and medium-skill households have the same mass in the ergodic distribution. Next, we target a persistence of residual earnings of 0.975 and a standard deviation of 0.51, following Floden and Lindé (2001). Next, we target the Gini index of wealth for the working-aged, as it emerges from the SCF. This, and normalizing the average skill of all working-age workers to unity, gives rise to skill levels $s_1 = 0.488$, $s_2 = 1.298$, and $s_3 = 11.6$ as well as the transition matrix between skills summarized in Appendix D.1.2.

3.2 Production

The parameters for the depreciation rate are $\delta_0 = 0.015$, $\delta_1 = 0.0169$ and $\delta_2 = 1.33$. The target for the curvature comes from Comin and Gertler (2006). The other parameters match a steady-state quarterly depreciation rate of 1.5 percent and unitary capacity utilization in the steady state, amid a real rate of return of 3.05 percent. Investment adjustment costs are indexed by $\phi_K = 10$, the mid-point of the range of estimates in Christiano et al. (2016). Wage persistence is set to $\phi_w = 0.837$, the estimate in Barattieri et al. (2014) for job stayers. For calibrating the parameters that govern job loss, we rely on the Current Population Survey (CPS). For each education group we calibrate $\lambda_x(e)$ and $\lambda_n(e)$ based on two targets: the average quarterly flow rate from employment to unemployment for each group, and the volatility of that rate relative to the volatility of the job-finding rate. For a given average job-finding rate (targeted below), the parameters emerge.[14] Since the U.S. economy's average unemployment rate during the Great Moderation is higher than the one we obtain from our cleaned CPS sample, we proportionally scale the separation rates afterwards to obtain a steady-state unemployment rate of 6 percent. We obtain $\lambda_x(e_L) = 0.048$, $\lambda_x(e_H) = 0.019$, $\lambda_n(e_L) = 0.114$, and $\lambda_n(e_H) = 0.056$. Conditional on a target for the labor income share (targeted below), we obtain hiring costs of $\kappa = 0.33$, matching function parameter $\alpha = 2.63$, and the steady-state wage per efficiency unit of labor $\overline{w} = 0.898$. The targets for these are a steady-state job-finding rate of 82 percent per quarter (as in the data), a steady-state job-filling rate of $q = 0.71$, as in den Haan et al. (2000), and costs per hire of about 50 percent of the average quarterly wage; see Silva and Toledo (2009).

[14] The average quarterly flow rate from employment to unemployment is given by $\lambda_x(e)+\lambda_n(e)(1-\mathbb{E}\{f\})$. The standard deviation of that flow rate is given by $\lambda_n(e)std(f)$, where $std(f)$ is the standard deviation of the job-finding rate. The relevant data moments in the CPS are reported in Appendix E.2.

We set $\psi = 179.4$ such that the Phillips curve's slope translates into a Calvo stickiness of 0.85, the estimate of Galí and Gertler (1999). We set the demand elasticity to a value of $\vartheta = 6$, implying a 20 percent markup over marginal costs. Last, we obtain the capital elasticity of production, $\theta = 0.2836$, and fixed costs of $\Xi = 0.125$, based on a target for the labor share (66 percent) and a steady-state investment-GDP ratio of 0.18.[15] The table in Appendix D.1.3 provides a summary of the parameterization of the production sector.

3.3 Central bank and fiscal authority

Interest-rate persistence is set to $\phi_R = 0.8$, a conventional value. The responses to inflation and unemployment, $\phi_\Pi = 1.5$ and $\phi_u = 0.15$, are based on Taylor (1993).[16] $\overline{\Pi} = 1.005$ implies a steady-state inflation rate of 2 percent annualized, in line with the Federal Reserve System's inflation objective. The unemployment target is $\overline{U} = 0.0462$. Since 77 percent of households in the calibration are of working age, this is line with a steady-state unemployment rate of 6 percent. $\overline{R} = 1.0126$ is in line with the 3.05 percent p.a. real interest rate, targeted earlier. Turning to fiscal policy, government consumption is a constant 19 percent of steady-state GDP, the average value in the data. Unemployment benefits replace 50 percent of earnings, with the relevant earnings capped at two-thirds of average economy-wide earnings, consistent with Shimer (2005) and Chetty (2008), and the literature surveyed in Graves (2020).[17] We index a household's retirement benefits to the education level of the household, which serves as a rough guide to lifetime earnings. Using the replacement schedule reported in Huggett and Parra (2010), the low educated have a replacement rate of 47 percent. This gives retirement benefits for the low educated of $b_{RET}(e_L) = 0.47 \cdot \bar{L}(e_L) \cdot \overline{w}$=0.32, where $\bar{L}(e_L)$ denotes the average productivity of a low-educated worker. For the high-education group, the replacement rate is 41 percent, meaning $b_{RET}(e_H) = 0.41 \cdot \bar{L}(e_H) \cdot \overline{w} = 0.46$. Social security taxes and unemployment insurance taxes

[15] The implied ratio of capital to quarterly GDP is 12. The ratio of wealth to quarterly GDP implied by the calibration is 13.58.

[16] Taylor (1993) has a response of annualized interest rates to the log output gap of 0.5. Regressing the CBO's measure of the output gap on unemployment, and realizing that the Taylor rule here is specified for quarterly interest rates, we arrive at the value for ϕ_u.

[17] Benefits are given by $b_{UI}(es) = \min(\overline{b}_{UI} \cdot e \cdot s \cdot \overline{w}, \overline{b}_{UI} \cdot 2/3$ steady-state average economy-wide earnings), with $\overline{b}_{\text{UI}} = 0.5$. After a household becomes unemployed, on average consumption falls by 11 percent, a value within the range of estimates in the literature; see, for example, Chodorow-Reich and Karabarbounis (2016).

are set to balance the respective transfer scheme in the steady state. The choices made here imply steady-state unemployment insurance and social security payroll tax rates of $\tau_{UI} = 0.015$ and $\tau_{RET} = 0.13$. We construct consumption and capital taxes from the National Income and Product Accounts as in Fernández-Villaverde et al. (2015). This gives tax rates on consumption and capital income of $\tau_c = 0.07$ and $\tau_d = 0.36$, respectively. For the functional form of labor-income taxes, we follow Gouveia and Strauss (1994) setting $\tau(X, w(X)es(1-l\varrho)) = \tau_{BC}(X) + \tau_0 \left[1 - (\tau_1 \left(\frac{w \cdot e \cdot s \cdot (1-l\varrho)}{\text{economy-wide avg. earn. in st.-st.}}\right)^{\tau_2} + 1)^{-1/\tau_2}\right]$. We follow the estimates of Guner et al. (2014) and set $\tau_0 = 0.182$, $\tau_1 = 0.008 \cdot (53,063/1000)^{\tau_2}$, and $\tau_2 = 1.496$.[18] $\tau_{BC}(X)$ then balances the rest of the budget both in the steady state and over the cycle. The table in Appendix D.1.4 summarizes the above parameterization for the government sector.

3.4 Parameterization of a RANK/TANK variant

For calibrating the shock processes and as a point of comparison, we will rely on a representative household (RANK) version of the model. We will, later, also compare the HANK model to a two-agent model (TANK). The calibration in both cases is identical to the one above, apart from the household structure. The RANK model has a large representative family of households of all ages, education levels, and employment states. We continue to target a real rate of 3.05 percent per annum, and so set the time discount factor for the RANK representative household to $\beta = 0.9925$. The TANK model has a split between spender households (that are exposed to idiosyncratic risk but cannot self-insure) and a family of savers. The savers represent 85 percent of the population and the spenders 15 percent. We choose 15 percent of spenders so as to match the share of households that hold zero net worth in HANK. This strategy is akin to Debortoli and Galí (2017). The time discount factor for the saver family is $\beta^{saver} = 0.9925$. In keeping with the HANK calibration, spenders in the TANK model have time discount factor $\beta^{spend} := \beta^{saver} - \Delta_\beta = 0.8825$. Appendix F provides details on the RANK/TANK model.

[18] Parameters are based on the "only-labor-income" case in Guner et al. (2014) (their Table 12). We re-normalize parameter τ_1 to reflect scaling. US$ 53,063 is the average income in their sample for the year 2000, on which the estimates are based.

Table I: Parameters for the shock processes

	ρ_{ζ_x}	σ_{ζ_x}
MEI shock, ζ_I	0.0	0.3478
TFP shock, ζ_{TFP}	0.95^a	0.0028
Monetary shock, ζ_R	0^b	0.0020
Wage shock, ζ_w	0^b	0.0073
Price-markup shock, ζ_P	0.8358	0.0545

Notes: All parameters estimated by maximum likelihood, unless noted otherwise. [a] calibrated based on Fernald (2014). [b] customary calibration. See the text for details.

3.5 Shocks

The steady-state values of the shocks are normalizations. We set $\overline{\zeta}_{TFP} = 0.717$ such that steady-state GDP is normalized to unity. $\overline{\zeta}_I = \overline{\zeta}_R = \overline{\zeta}_w = \overline{\zeta}_P = 1$ to normalize the corresponding shocks such that they have zero mean in logs. We set $\rho_{\zeta_{TFP}} = 0.95$, so as to match the persistence of utilization-adjusted TFP in Fernald (2014). We set the persistence of the wage-markup shock to $\rho_{\zeta_w} = 0$ (the shock is already propagated through wage persistence). As is customary, the monetary shock is white noise, too, $\rho_{\zeta_R} = 0$.
For the remaining parameters of the shock processes, the literature provides less guidance. We estimate the laws of motion for the shocks using maximum likelihood and the RANK model, linearized, on time series data for our calibration sample. The time series are: the growth rate of real consumption, the growth rate of real investment, the growth rate of the real wage, the nominal interest rate, the inflation rate, and the unemployment rate. All series are demeaned. Appendix E.3 provides the exact definition of the data sources. We allow for iid measurement error in each of the observation equations, setting the variance of the measurement error equal to 1 percent of the underlying series' unconditional standard deviation. Table I summarizes the resulting parameter values for the shocks. These values are used in all the model variants (HANK/RANK/TANK).

3.6 Properties of the calibrated model

Appendix D provides further information about the calibrated HANK model. Appendix D.3 shows that the model closely matches the wealth distribution in the U.S. economy, both for working-age households and for the retired. Appendix D.4 documents that U.S. households' sources of income differ starkly by net worth and age and that the model matches this salient feature rather well. Appendix D.5 shows business cycle moments in the model and the data. The model matches the business cycle features well, too. Appendix D.6 shows impulse responses to all shocks. Appendix D.7 shows a variance decomposition. The MEI shock works like a demand shock. It generates comovement in the GDP aggregates, employment, interest rates, and inflation. The MEI shock accounts for about half of the variance of GDP, the TFP shock for about a third. Price- and wage-markup shocks account for about half the fluctuations in prices and wages, respectively. Appendix F.9 shows the marginal propensities to consume (MPC) for different groups of households.[19]

4 A political economy of systematic monetary policy

We are now in a position to assess the distributional effects of *systematic monetary stabilization policy*. Section 4.1 describes the policies we consider. Section 4.2 shows that the choice of policy can have substantial welfare consequences for the individual household. Section 4.3 shows that monetary policy in the model is not neutral in the long run and discusses why. Section 4.4 shows the transition dynamics induced by a change in monetary policy. Section 4.5 provides a comparison with the RANK/TANK models. Section 4.6 summarizes the sensitivity analysis we have conducted.

4.1 The policy experiment: Optimal simple policies

Our policy experiment asks households: "Relative to the *status quo*, would you want a change toward a different systematic monetary stabilization policy?" Toward this end, we look at an unanticipated, permanent change in the parameters of monetary policy rule (4). We focus on a grid of parameters, the grid points being $\phi_\Pi \in \{1.5, 2, .., 3.5, 4, 5, 6, ..., 10\}$ and $\phi_u \in \{0, 0.25, 0.5, ..., 3\}$. In practice, this covers a wide range of different policies and stabilization outcomes. We keep $\phi_R = 0.8$ as in the calibrated baseline, and—as is customary—we set monetary policy shocks to zero throughout ($\sigma_{\zeta_R} = 0$). The *status quo* is

[19] The working-paper version, Gornemann et al. (2021), also documents that the cross-sectional skewness of earnings growth in the HANK model is countercyclical, in line with Guvenen et al. (2014).

the calibrated baseline ($\phi_\Pi = 1.5$, $\phi_u = 0.15$, $\phi_R = 0.8$, with $\sigma_{\zeta_R} = 0$). The starting point for both the welfare comparisons and the transition effects is the ergodic mean under the *status quo* policy. Changing the policy rule alters the economy's ergodic distribution and thus also the ergodic mean. We do not wish this to translate into a different implicit inflation target (with firms permanently indexing to the wrong long-run inflation level). Therefore, we always adjust the Taylor rule's intercept such that the average inflation rate remains at exactly 2 percent annualized, under all policies (including the baseline).[20]

4.2 Disagreement about stabilization policy

In discussing the distributional effects of the different monetary policy rules, it will be convenient to pick evocative labels. We define "classes" of households by net worth and age. *Poor households* henceforth are the 20 percent poorest households by net worth. *Middle-class households* are the households whose net worth falls into the 40th to 60th percentile of the net worth distribution. *Rich households* are the 5 percent with the highest net worth. When looking at age, we distinguish *young households* (those of working age) from *retired households*. Note that there may be overlap between these groups. For example, a young household may also be poor, middle-class, or rich.

The first block of rows of Table II shows the parameters of the monetary policy that maximizes utilitarian welfare for each class of households, that is, the policy this class prefers switching to most. The next block shows the implications of these policies for stabilizing the business cycle. The remaining rows show the welfare consequences for different classes of households and the share of households that favor the respective policy over the baseline. There are three results. First, there is a notable gradient of policy preferences by net worth; second, there is a notable gradient by age; third, small aggregate consequences of a policy change can hide substantial welfare consequences for the individual household.

The first observation is that there is a notable gradient of policy preferences by net worth. To see this, compare the policies favored by the poor and the rich. Poor households favor a monetary policy aimed at stabilizing unemployment ($\phi_\Pi = \phi_u = 2.5$, first column). Rich households, instead, favor exclusively an inflation-centric policy ($\phi_\Pi = 10$, $\phi_u = 0$, third

[20] Appendix G describes the algorithm we use to compute the adjustment.

Table II: Who prefers what systematic stabilization policy?

		wealth poor	middle	rich	*all*	age young	retired
Policy	ϕ_Π	2.50	3.50	10.0	8.00	4.00	10.0
	ϕ_u	2.50	0.50	0.00	1.25	1.25	0.00
Std	Π	1.31	0.82	0.25	0.74	0.99	0.25
	u rate	0.25	0.77	1.69	0.85	0.54	1.69
Welfare gain (% of cons.)	poor	0.03	-0.01	-0.19	-0.04	0.01	-0.19
	middle	-0.05	0.03	-0.05	0.03	0.02	-0.05
	rich	-0.06	0.09	0.22	0.15	0.05	0.22
	all	-0.03	0.03	-0.01	0.03	0.02	-0.01
	young	-0.004	0.02	-0.10	0.01	0.02	-0.10
	retired	-0.12	0.10	0.26	0.16	0.03	0.26
In favor (%)		41	63	40	53	100	40

Notes: Changing policy to a rule that is optimal for a specific subset of the population. From left to right: policy that maximizes utilitarian welfare for the poor (0-20th percentile of net worth), the middle-class (40-60), the rich (95-100), all households, the young and the retired. From top to bottom: parameters of the simple rule that maximizes utilitarian welfare for the respective class of households; the standard deviation of inflation (ann. p.p.) and the unemployment rate (p.p.). Then, average consumption-equivalent welfare gains for other classes of households. Last, share of households in favor of the change to the respective policy. Entries rounded to the last digit shown.

column). Under the policy for the poor, the unemployment rate is only about a third as volatile as in the baseline (first column, second block).[21] Under the policy for the rich, instead, the unemployment rate is twice as volatile as in the baseline and, thus, about six times as volatile as under the policy for the poor. The mirror image is the volatility of inflation. Under the policy favored by the rich, the volatility of the inflation rate is only about a fifth of the volatility observed under the policy for the poor. A policy that maximizes utilitarian welfare across all households is in between these extremes (see fourth column "all"), as is policy aimed at the middle-class (second column).

The second observation is that there is a strong gradient by age. Working-age households (the "young") favor a policy that implies more unemployment stabilization than in the baseline ($\phi_\Pi = 4$, $\phi_u = 1.25$, fifth column). Indeed, young households' policy preferences appear half-way between those of the middle-class and the poor. Retired households, instead, prefer the same inflation-centric policy as the rich ($\phi_\Pi = 10$, $\phi_u = 0$, final column).

The third observation is that the aggregate consequences of a policy change can hide substantial disagreement. For example, a change toward a policy that maximizes utilitarian

[21]Moments under the baseline policy are shown in Table D9 in the appendix.

welfare over the entire population of households (column "all") leads to average welfare gains equivalent to 0.03 percent of lifetime consumption (block "Welfare gain," row "all").[22] This hides, though, that the poor are opposed to the policy change, whereas the rich stand to gain from it. Namely, the poor would be willing to *pay* 0.04 percent of their lifetime consumption to *avoid* the policy change. The rich, instead, would receive a *gain* equivalent to 0.15 percent of lifetime consumption. Aggregate welfare, thus, can be an incomplete guide to the distributional effects of systematic monetary stabilization policy.

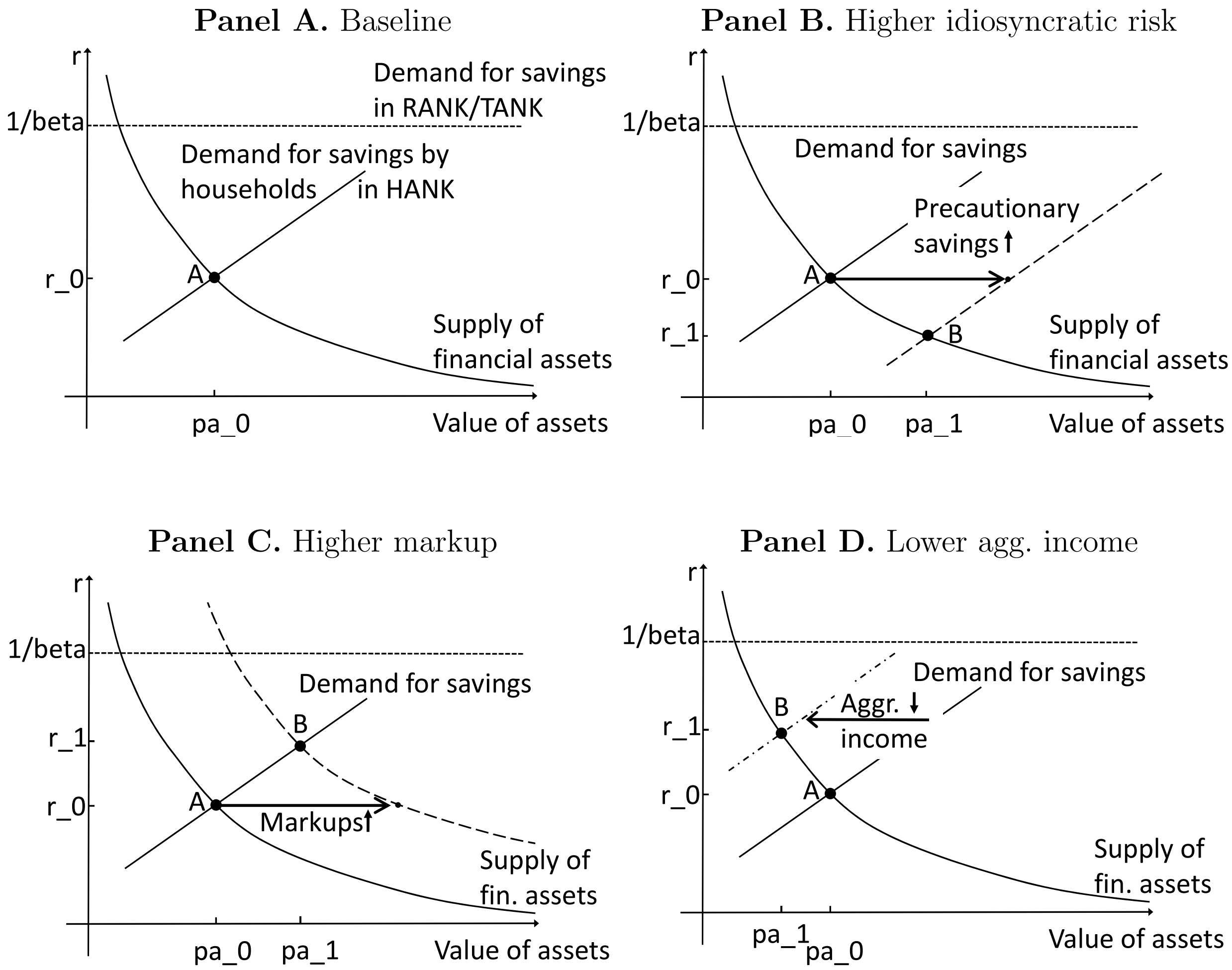
One can see this even more clearly when focusing on the policy targeted at the rich. On average, this policy leads to small welfare *losses* (equivalent to a 0.01 percent fall in lifetime consumption; see column "rich," row "all" of Table II). The distributional consequences are striking, regardless. Namely, the rich would *gain* the equivalent of 0.22 percent in lifetime consumption (row "rich"), while the poor would have a *loss* of roughly equal size (row "poor").[23] A comparable—if quantitatively smaller—disagreement arises with a monetary stabilization policy tailored to the poor (column "poor").

The disagreement means that rather different policies enjoy sizable political support; see the final row of Table II. A change toward the policy targeted at the rich or toward the policy targeted at the poor both have the support of about 40 percent of households. A change toward the policy under the utilitarian welfare objective would gain the support of 53 percent of households. A change toward the policy targeted at the middle-class would garner larger support, still. And the largest support (in the set of policies considered here) would be commanded by a move toward the policy favored by the young, under which virtually all households would see some welfare gains over the baseline policy.

[22] The consumption-equivalent gain for a household is the percentage increase in the household's consumption under the baseline policy (in all current and future states) that makes the household indifferent between the policy change and remaining with the baseline policy. One can think of this as a household-specific proportional consumption subsidy or tax due for the rest of time.

[23] The consumption-equivalent gains can be converted into a dollar value by computing the expected present value of consumption-equivalent gains (using the model's discount factor). In dollar terms, the policy for the rich induces an average gain of about 22,000 year-2004-US$ for a rich household. The average poor household loses about 4,000 year-2004-US$. This reflects the fact that the rich have higher lifetime consumption.

Figure 2: Supply and demand for financial assets



Notes: Supply and demand effects on the equilibrium supply of financial assets and the risk-free rate. See the text for further details.

4.3 Long-term effects of systematic monetary policy

Monetary stabilization policy affects both the average incomes and the risks that households face. A change in systematic monetary stabilization policy, thus, affects the ergodic distribution of the economy. Such changes, in turn—in the HANK environment, with its Bewley-Imrohoroglu-Huggett-Aiyagari core—are intermediated through the interplay between the demand for financial savings by households and the supply of financial assets. The current section focuses on these long-run effects that a change in *systematic* monetary stabilization policy brings about.

Figure 2 illustrates these changes schematically. The total supply of financial assets in the economy is given by the present discounted value of future dividends of the mutual funds. The mutual funds in the current model pool the cash flows from three types of long-lived assets: they derive cash flow from long-term employment relationships with the employment agencies, from owning productive capital through capital-services firms, and from being able to charge markups over marginal costs through the differentiated goods producers. We begin our discussion of Figure 2 with Panel A (top row, left). The x-axis gives the value of assets, the y-axis the real rate of return. The solid downward-sloping line shows the supply of financial assets, that is, the market value of the mutual funds' shares. This line slopes downward for two reasons. The first is that, for a given stock of employment and capital, the higher the real rate of interest is, the more are future cash flows discounted and the lower is the market value of the financial assets. The second reason is that the higher the real interest rate is, the higher is the required return on capital and the lower is the capital stock that capital-services firms accumulate. Of course, the same effect, for a given wage, is at work for employment relationships. Thus, a higher real interest rate reduces the total value of financial assets. The other lines in Panel A refer to the demand for financial savings by households. The demand curves depend on the model environment. The dotted horizontal line at a real rate of $1/\beta$ marks the demand for savings in RANK/TANK. In these environments, there either is no idiosyncratic risk to start with or the households that face such risk do not have access to financial markets. The only consideration that matters for the demand for savings, then, is the return on assets relative to time preferences. This means that the demand for financial assets in RANK/TANK is perfectly elastic, approximately at least. In HANK, instead, households save for reasons other than the return on assets alone. For a given level of income, in order to hold more financial assets by value, households in HANK have to be enticed by a higher real return. That is, households' demand for savings is not perfectly elastic and the demand curve for savings in HANK is upward-sloping. The equilibrium real interest rate and value of assets (with a commensurate capital stock and employment) emerge where the demand for savings and the supply of financial assets intersect. For the HANK model, this is at point A in the graph.

It is important to observe that systematic monetary stabilization policy can affect both the supply of financial assets and the HANK households' demand for savings. Panels B through D of Figure 2 illustrate the ensuing effects. Panel B of Figure 2 (top row, right) shows schematically the effect of an autonomous rise in idiosyncratic risk. In HANK, if idiosyncratic risk rises, households' demand for savings increases. To clear the market for financial assets, the real rate has to fall. This fall in the real rate stimulates investment by firms in physical capital. The capital stock expands, and with it the economy's supply of financial assets by value rises. The economy transitions from point A to point B in the graph. Systematic monetary policy shapes idiosyncratic risk in the model: a policy rule that is more inflation-centric tolerates a larger volatility of (un)employment (compare Table II). Besides this, it is well-established that search and matching models give rise to a link between the extent of cyclical fluctuations of unemployment and higher average unemployment.[24]

Panel C (bottom row, left) shows the effect of an autonomous increase in the economy's supply of financial assets, as may, for example, arise from an increase in markups.[25] When markups rise, all else equal, the profits of firms rise. The value of financial assets rises—for a given stock of capital and employment. In order to induce households (the ultimate owners of the mutual funds) to hold the increased supply of assets, in equilibrium the real rate of return needs to rise. Higher real rates discourage investment, so that also falling productive capacity helps realign the supply of financial assets with demand, point B in Panel C.

In the model at hand, indeed, the more inflation-centric monetary policy is, the higher are average markups. Appendix I shows formally how this arises from the New Keynesian Phillips curve and price-markup shocks. The intuition for the effect is as follows. Nominal rigidities mean that price setters anticipate the risks that the business cycle brings to their profitability. They adjust their markups accordingly. Consider a negative aggregate shock to price markups (a rise in the elasticity of demand). Such a shock is disinflationary. If monetary policy seeks to stabilize inflation in the face of this negative price markup shock (as an inflation-centric policy would do), monetary policy has to stimulate demand. On the side of price-setting firms, this raises marginal costs at a time of low markups. The firms, thus, face the risk of attracting demand precisely when their marginal costs are high. Knowing

[24]More cyclicality means that job-finding rates are high when the pool of the unemployed is small (in a boom) and low when the pool is large (Jung and Kuester 2011, Hairault et al. 2010, or–with downward wage rigidity–Dupraz et al. 2019). Hairault et al. (2010), in addition, discuss that fluctuations in the probability of separating from firms (which is constant in our paper) would have little effect on average unemployment.

[25]The panel abstracts from direct effects of markups on economic activity, focusing only on the effects that arise through the supply of financial assets. Panel D looks at the omitted direct effects on income.

that there may be markup shocks in the future, price setters, therefore, precautionarily choose higher average markups to start with. To the best of our knowledge, consideration of the markup channel is new to the HANK literature.[26]

In a production economy like ours, there will be "second-round" effects on the demand for savings that Panels B and C of Figure 2 have deliberately ignored. In particular, whenever productive capacity is affected, household incomes also change. Panel D of Figure 2 (bottom row, right) shows the effect that an autonomous, permanent fall in household incomes has on the market for financial assets, a fall that could, for example, have been triggered by a rise in markups as in Panel C. A fall in permanent income, amid consumption smoothing, means that households cut back their demand for savings. So as to ensure equilibrium in the market for financial assets, the real rate needs to rise and the supply of financial assets needs to fall (and, thus, once more the capital stock falls), until the economy settles at point B, at a higher real rate and less productive capacity.

Against the background of this intuition, Table III summarizes the quantitative effect that the policies of Table II have on the long-run means of selected endogenous variables in HANK. The two polar ends of the spectrum illustrate the effects that are at work. Focus,

Table III: The long-run effects of the optimal policies

		wealth				age	
		poor	**middle**	**rich**	*all*	**young**	**retired**
Policy	ϕ_Π	2.50	3.50	10.0	8.00	4.00	10.0
	ϕ_u	2.50	0.50	0.00	1.25	1.25	0.00
Means	capital stock (%)	0.46	-0.43	-2.19	-0.80	-0.15	-2.18
	real rate (p.p. ann)	-0.02	0.002	0.022	0.004	-0.004	0.022
	asset price (%)	-0.01	-0.09	-0.86	-0.24	-0.07	-0.86
	unempl. rate (p.p.)	-0.05	0.02	0.18	0.04	-0.01	0.18
	markup (p.p.)	-0.09	0.02	0.23	0.04	-0.03	0.22
	wage (%)	0.10	-0.08	-0.43	-0.15	-0.02	-0.43

Notes: Change in average outcomes implied by the policies shown in Table II. The first block shows the policy parameters that characterize the rule. Thereafter: Change in long-run average capital stock, wage, and stock price (in percent); change of average unemployment rate and average markups (p.p.); and change in real interest rate (annualized p.p.); each induced by a change toward the policy that is optimal for the respective class of households. Negative numbers mean that the respective variable in the long term falls relative to the baseline. By design, the average inflation rate is not affected by a policy change. The table, therefore, does not show the average inflation rate.

[26] The channel has been explored in other contexts, for example, in Fernández-Villaverde et al. (2015) in the context of uncertainty shocks.

first, on the policy that is targeted to the poor (left column of Table III). The policy stabilizes unemployment and allows inflation to fluctuate. The average unemployment rate, as a result, is lower (rather than at 6 percent it is 5.95 percent). Average markups are lower, too (rather than at 20 percent, they are at 19.91 percent). The capital stock is larger and the wage higher (by 0.46 percent and 0.10 percent, respectively). That is, the monetary policy preferred by the poor leads to higher average economic activity.

The policy aimed at the rich, instead, has the opposite implications (third column of Table III). It sees the unemployment rate rise from an average of 6 percentage points to 6.18 percentage points. And it sees average markups rise from 20 percent to 20.23. The capital stock drops strongly, by about 2.2 percent. In line with the fall in capital, the wage declines as well, namely, by 0.4 percent. In sum, aggregate incomes fall notably and permanently. The decline in average incomes reconciles the fact that markups rise with the fact that the long-run average price of the asset falls nevertheless (recall also the discussion of Panel D of Figure 2).

The policies, thus, affect the distribution of incomes and income risks. Since households differ in their exposure to labor income and capital income (to dividends as much as to capital gains), and in their exposure to unemployment risk, the changes documented above have distributional consequences.

4.4 The transition to the new ergodic distribution

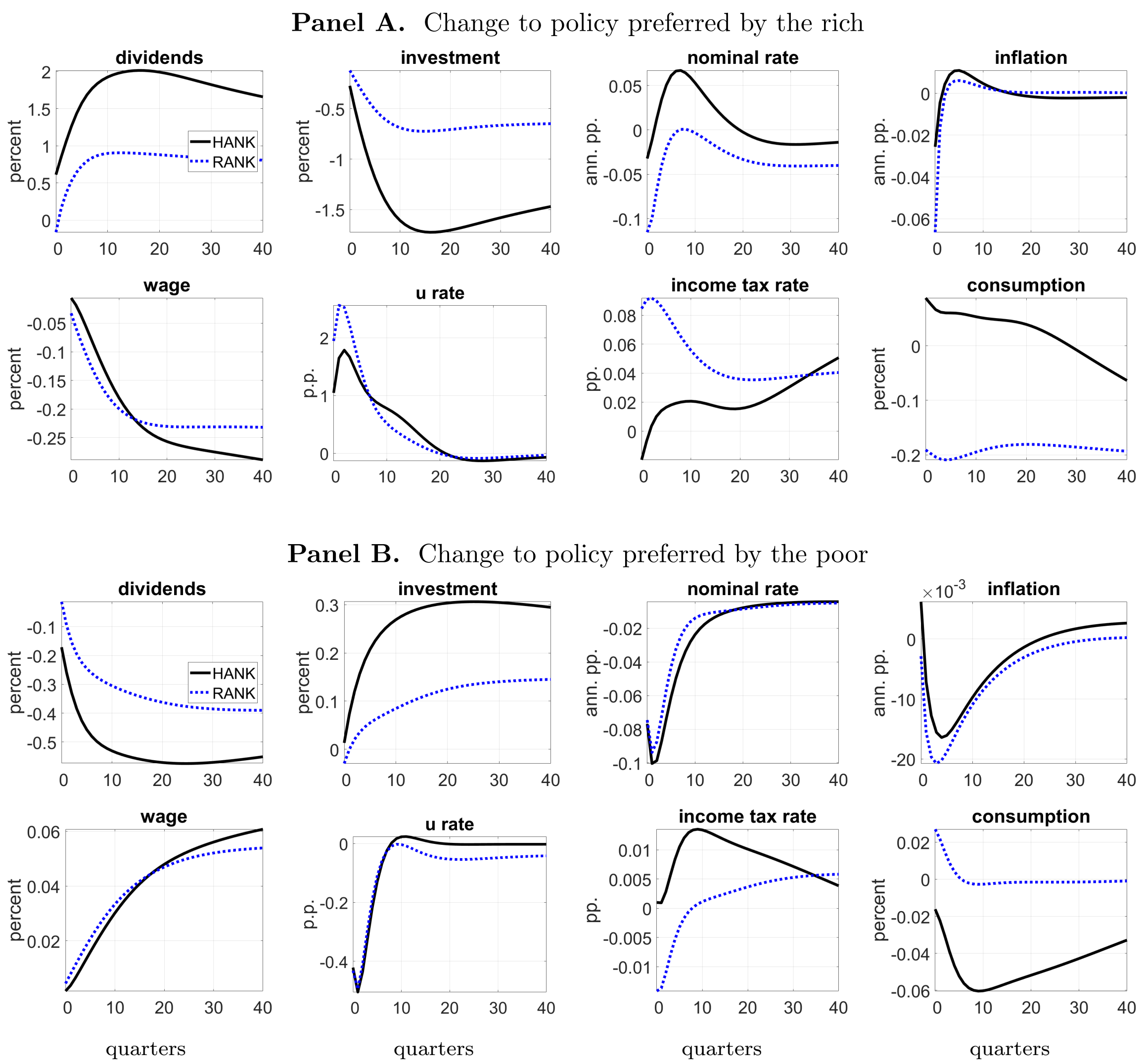
The change in monetary policy sets in motion a transition to a new ergodic distribution of the economy. The transition phase is important because this is where a lot of the disagreement between households arises. If, instead, the economy were to jump from one ergodic distribution to the other (with households preserving their ownership of shares in the mutual funds), there would barely be any disagreement about systematic monetary stabilization policy: the capital stock would be lower and capital owners would not receive the *temporary* rise in dividend payouts that comes with lower investment.[27]

Figure 3 zooms in on the transition effect, showing the first 10 years (40 quarters) after a

[27] Abstracting from the welfare gains/losses in the transition phase, almost all households would prefer the monetary policy of $\phi_\Pi = \phi_u = 2.50$ that the poor preferred in Table II. Further details are available upon request.

change in policy is announced and implemented. Toward this end, the figure shows the effect that the policy change has on average outcomes during that period. The lines show how, at the time of the policy change, economic agents in the model would expect the policy change to affect the economy on average going forward, accounting fully for the possibility of future shocks.[28] The solid lines in Figure 3 show the transition effect in the HANK economy. For comparison, each of the panels also shows the transition effect that would prevail in the RANK counterpart of the model (dashed lines). The transition in TANK looks very similar to that in RANK and is, therefore, omitted.

Figure 3: Transition induced by a change in monetary policy



Notes: Expected transition effect after change in policy. Panel A: change to policy preferred by the rich. Panel B: change to policy preferred by the poor. Quarter 0 is the quarter of the policy change. HANK: solid black line, RANK: dashed blue line.

Panel A of Figure 3 shows the transition effect after a change toward the inflation-centric

[28]Appendix H provides details on the algorithm that is employed to compute the transition effects.

policy favored by the rich. The first row shows variables that relate to financial income. The change in policy means a change in the profitability of firms: it comes with rising markups and windfall gains to financial wealth (upon the change of policy, the asset price rises by about 0.4 percent in HANK and by about 1 percent in RANK, not shown).[29] Dividends increase in both the HANK and the RANK economy (top row, left column). They rise because of higher markups and because investment falls. The increased distortions due to higher markups mean that even in the RANK economy investment declines by about half a percent (first row, second column). The fall in investment is three times as large in HANK, however. The reasons for this are provided in the earlier discussion of Figure 2's Panels C and D. Namely, the windfall gains to net worth raise the supply of financial assets. In HANK, this puts pressure on the real interest rate and leads firms to further reduce productive capital. The fall in aggregate incomes that follows lowers capital and investment yet more. As a result of the stronger fall in investment, dividends, thus, rise more strongly in HANK. The fall of the capital stock in HANK is in line with the fact that the HANK economy converges to a higher real rate of return than the RANK economy (first row, the difference between the graphs in the third and fourth columns).

The second row of Panel A shows the transition of variables related to after-tax labor income. The fall in the capital stock that follows after a move toward the policy favored by the rich comes with a drop in output and, thus, a sluggish decline in the wage (second row, left column). This means that early in the transition the unemployment rate rises sharply: in the HANK model it increases by about 2 percentage points while rising even more in the RANK model (second row, second column). The third panel of the second row shows the response of income taxes. Initially the rise in dividends (which are taxed) raises government revenue in HANK enough so that labor taxes can be reduced in spite of rising outlays for unemployment insurance. Eventually, however, labor taxes need to rise to pay for the increased cost of unemployment benefits amid a lower labor tax base. The final panel (second row, right column) shows the response of consumption. Interestingly, in line with the labor tax cut and windfall gains to capital, there is a short-lived consumption

[29] The working-paper version of the current paper, Gornemann et al. (2021, Appendix S), provides a detailed decomposition of the asset price response under an inflation-centric policy.

boom in HANK. This boom is specific to HANK. It happens amid a fall in employment and amid falling output (the latter is not shown here). It bears noting that in HANK, the asset holders (who receive the windfall gains) are not necessarily patient. Indeed, many owners of shares have high MPCs, so that for the average owner of shares (using wealth weights to average), the marginal propensity to consume out of wealth over the course of a year is about 8.5 percent compared to only 3.1 percent in RANK (see Appendix F.9 for the MPCs). Panel B of Figure 3 shows the transition effects that are induced by a change in policy toward what is preferred by the poor. While smaller in magnitude, the effects are largely the mirror image of Panel A. What seems noteworthy (and consistent) is that a transition toward a policy aimed at the poor raises economic activity on net (not shown), reduces unemployment (bottom row, second column of Panel B) but—in HANK—initially does not raise aggregate consumption (solid line final row, right column).

4.5 Comparison to RANK/TANK

We have built a HANK business-cycle model with substantial heterogeneity and have found considerable disagreement about the preferred shape of monetary stabilization policy. The current section explores the two simpler model variants: the RANK model and the TANK model. To recall, the RANK variant is the large-family version of the HANK model. The TANK variant has a split between spender households and a family of savers. The savers represent 85 percent of the population and the spenders 15 percent. The latter is in line with the 15 percent share of borrowing-constrained households in the HANK model's calibration. Table IV is the RANK/TANK counterpart to Table II. The first column shows the optimal policy for RANK and its implications for the business cycle and welfare. The second column shows the policy that maximizes utilitarian welfare of the group of spenders in TANK. The third column shows the policy preferred by the TANK family of savers.[30] Table II shows the comparable entries for the HANK model, from which the current table reports the utilitarian welfare-maximizing HANK policy as a point of reference (fourth column).

[30] Table IV evaluates welfare in RANK/TANK on the same grid of policies that was used for the HANK economy (in Table II). The width of the grid explains why here the policy preferred by RANK households and the TANK savers is identical. A finer grid would not lead to a change in economic substance. The disagreement between the two models is quantitatively minor.

Table IV: Optimal policies in RANK/TANK

			RANK	TANK spender	TANK saver	HANK all
Policy		ϕ_Π	1.5	1.5	1.5	8.00
		ϕ_u	0.5	2.0	0.5	1.25
Std (HANK)		Π	1.17	1.41	1.17	0.74
		u rate	0.51	0.22	0.51	0.85
Welfare gain (% of cons.)	HANK	poor	0.02	0.02	0.02	-0.04
		middle	-0.03	-0.09	-0.03	0.03
		rich	-0.05	-0.12	-0.05	0.15
		all	-0.02	-0.06	-0.02	0.03
		young	-0.02	-0.03	-0.02	0.01
		retired	-0.09	-0.22	-0.09	0.16
		RANK	0.02	0.001	0.02	-0.07
		TANK, spender	0.05	0.06	0.05	-0.09
		TANK, saver	0.01	-0.01	0.01	-0.06
In favor in HANK (%)			44	34	44	53

Notes: Same as Table II, but reporting optimal policies for the RANK economy and for TANK savers and spenders. The final column repeats the optimal utilitarian policy in HANK. The rows report the second moments that the respective policy implies (in HANK), and the welfare gains that the policy brings to the different types of households in the three different types of models. The final row shows the support the policy would command in HANK.

Three observations are noteworthy. First, what the RANK and TANK economies miss is the sizable support for *inflation-centric* policies that emerges from the HANK economy. In particular, all three of the RANK and TANK optimal policies result in less inflation stabilization (and more unemployment stabilization) than the utilitarian policy aimed at all HANK households. Second, the sizable distributional implications of systematic monetary policy for the *saver* go entirely unnoticed in the TANK economy. Modeling the exposure to the different sources of income–in the current context–is, thus, essential for analyzing the political support for and the distributional consequences of different stabilization policies. Third, while TANK provides a poor approximation for the saver, the optimal policy for the TANK spenders–in terms of aggregate and welfare implications–approximates the optimal policy for the poor in HANK reasonably well.

Table V provides a way of also comparing the long-term effects of policy changes in HANK to RANK/TANK. Namely, in RANK/TANK, the table shows the long-term effect of a change toward the policies that the HANK poor, middle-class, or rich prefer. Comparing the entries

Table V: Long-term effects of monetary policy in RANK/TANK economies

HANK policy for	poor		middle		rich	
ϕ_Π	2.50		3.50		10.0	
ϕ_u	2.50		0.50		0.00	
Effect on means in	**RANK**	**TANK**	**RANK**	**TANK**	**RANK**	**TANK**
capital stock (%)	0.03	0.03	-0.12	-0.12	-0.40	-0.41
real rate (p.p. ann)	-0.008	-0.008	-0.006	-0.006	-0.03	-0.03
asset price (%)	-0.39	-0.39	0.20	0.20	0.84	0.83
unempl. rate (p.p)	-0.04	-0.04	0.02	0.02	0.17	0.17
markup (p.p.)	-0.08	-0.08	0.03	0.02	0.22	0.21
wage (%)	0.06	0.06	-0.05	-0.05	-0.26	-0.26

Notes: Same as Table III but showing the effect of the respective policies in the long term in the RANK and TANK economies, respectively. Shown are the long-term effects in the RANK/TANK economies of HANK policies designed for the poor, the middle-class, and the rich.

here to the three left-most columns in Table III, which show the long-term implications of the same policies in HANK, there are three observations again. First, across all three models (RANK/HANK/TANK) the effect that the different policies have on average markups is virtually identical. This is the case as all three models share the same Phillips curve, from which the effect arises. Similarly, second, all three models show a comparable effect of policy on average unemployment rates. This again seems reasonable given that in all three models the policies have comparable effects on the cyclical fluctuations in unemployment (numbers not shown here). Instead, third, what differs strongly between RANK/TANK and HANK is the long-term effect that systematic monetary stabilization policy has on the capital stock. For inflation-centric policy, capital falls by barely 0.4 percent in RANK/TANK as opposed to the 2.2 percent fall observed in HANK. This difference is consistent with the HANK model's Bewley-Imrohoroglu-Huggett-Aiyagari core: the windfall gains to financial wealth further crowd out capital–an effect that is absent from RANK/TANK (recall Panels C and D of Figure 2). The stronger effect of systematic monetary stabilization policy on the capital stock in HANK also comes with a stronger effect of policy on the wage. Last, the economies differ in their response of the real rate of interest and the asset price. In HANK, under inflation-centric policy, the average real rate is 0.05 percentage point higher than under the same policy in RANK/TANK.[31] The stronger crowding out of capital in HANK is also

[31]The text focuses on the *difference* in average real rates between Tables III and V. Since all of the models are non-linear, in RANK/TANK, too, the average real rate can be and is affected by policy.

rather evident when comparing the long-term effect of policy on the asset price. Under an inflation-centric policy, in RANK/TANK the average price of a share rises (recall that markups rise). In the HANK economy, instead, the asset price falls relative to the baseline.

4.6 Further analysis and sensitivity

Counterfactuals require solving the entire model for each parameterization. They are, thus, computationally costly. That said, the working-paper version of the current paper, Gornemann et al. (2021), shows extensive further analysis and sensitivity checks. Since the modeling and calibration there only marginally deviate from the current paper's modeling and calibration, we summarize those results here.

To begin with, we looked at which shocks are behind the disagreement. Toward this end, we computed the welfare assessment of different groups of households if only one shock is present at a time, for selected policies. In the exercise we do, the main driver of household disagreement appears to be the price-markup shock, the shock that links inflation stabilization and the average markup.

For all of the remaining sensitivity checks, we looked at only one policy change, namely, the one that leads to the largest disagreement in the baseline: a move toward an inflation-centric policy. More in detail, we focused on a policy of no inflation variability ($\Pi_t = \overline{\Pi}$). In this setting, we looked at the sensitivity with respect to fiscal policy. In the current paper, a move toward an inflation-centric policy leads not only to higher unemployment but also to higher labor taxes (due to the higher outlays for unemployment benefits). This burdens labor twice. In a counterfactual, we had labor and dividend taxes move in lockstep to finance the government budget. This slightly raised the support for inflation-centric monetary stabilization policy in the middle-class; the poor, though, remained firmly opposed.

In a third counterfactual we assumed that households did not hold a mutual fund only but that household portfolios are composed of both (long or short) short-term nominal positions and shares of a mutual fund. To each household we assigned the portfolio weights in bonds and shares that emerge in the data. That is, we assigned portfolio shares by age, education, and net worth, from the SCF. In this counterfactual, the support for inflation-centric policy reached even further into the middle class than in our baseline. The reason is that, in the data, the young middle-class households (who are the marginal households) tend to hold highly levered portfolios. Under the alternative portfolio structure, they receive a larger share of the financial windfall gains that come with inflation-centric policy than their net worth alone would suggest.

Fourth, we assessed the role of wages. The wage rule determines how, in the long run, a rise in markups is passed on to workers or owners of capital. Hence, wage setting is important. Namely, if wages fall but not employment, this hurts only workers. Instead, if employment falls, this hurts workers but it also hurts the rich through a lower marginal return to capital. The results shown in the main text illustrate a case when the burden of adjustment is on the wage (the effect of policy on average unemployment was comparable in HANK and RANK/TANK, Tables III and V, despite the different impacts on the capital stock). In a scenario where wages fell, but–by construction–less than one-for-one with economic activity (and thus less than in our baseline), we found somewhat less support for an inflation-centric policy, though the wealth gradient in policy preferences remained. We also looked at another scenario where wages were set such that the long-run labor share in GDP remained constant by construction—in spite of the rise in markups. Then, support for an inflation-centric policy vanished entirely, even among the rich, and it was the middle-class that had the largest welfare loss from such a policy. In this case, though, the burdens of adjustment lay heavily with employment (and, thus, the marginal return on capital): the move toward an inflation-centric policy raised the unemployment rate by a full percentage point (five times more than in the baseline).[32] A wage rule modelled on Nash bargaining, instead, delivered results that were comparable to the baseline in the current paper.

Fifth, we assessed if who bears the cost of inflation variability is important. A long literature in monetary economics discusses whether the costs fall on households or firms. The baseline assigns price adjustment costs to owners of firms. We ran a counterfactual in which the government compensates firms lump-sum for the price adjustment costs, so that the costs are financed by labor taxes. The views on an inflation-centric policy only became slightly more balanced. The wealth gradient in policy preferences remained: price adjustment costs

[32]It is important to bear in mind that the markup that firms charge is a markup over marginal costs; that is, it is a markup both on the rental cost of capital and on the price of labor. If the wage does not move, firms are not compensated for the rise in distortions that comes with higher markups.

themselves do not appear to drive the disagreement about policy that we document above.

5 Conclusions

Monetary policy affects aggregate economic activity, the distribution of income, and the income risks that households face. To assess the distributional effects of the systematic conduct of monetary policy, we have built a New Keynesian heterogeneous-agent DSGE model that features asset-market incompleteness; heterogeneity in preferences, skills, and age; a frictional labor market; and sticky prices. The model was calibrated to the U.S. in tranquil times.

The main finding is that households may strongly disagree as to how monetary policy should *systematically* respond to the business cycle. The disagreement can be traced to households' net worth and to how important wages are as a source of income to households. The exposure to labor income matters because an inflation-centric monetary policy tolerates larger fluctuations in unemployment. Such fluctuations then translate into higher average unemployment. Recipients of labor income, thus, have both higher average and higher cyclical unemployment risk and they have lower lifetime income. Households' net worth in turn matters because monetary stabilization policy affects the value of financial assets. In the model, firms face shocks to price markups. A monetary policy that stabilizes inflation in the face of such shocks raises the risk that firms attract demand precisely when their marginal costs are high. If monetary policy is inflation-centric, firms thus choose higher average markups to start with. The households that gain from this are the net-worth-rich (for whom labor income is a small part of lifetime income) and retirees (who tend to have assets, but are not exposed to labor income). Nominal redistribution does not play a role in these results. The results emerge with real assets only and when fixing the average inflation rate at 2 percent p.a. throughout.

The findings above are conditional on tax policies that do not allow fiscal policy to have a targeted response to monetary-induced changes. The paper has also abstracted from an active management of government debt. Future work that looks into these dimensions might bring important insights into the political economy of the monetary and fiscal *policy mix.*

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Online appendix to

"Doves for the Rich, Hawks for the Poor? Distributional Consequences of Monetary Policy"

(not for publication)

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A Further details on the model

This appendix collects material concerning the model description that the main text relegated to the appendix.

A.1 Value of a newborn household

This section provides the value of a newborn household, that Section 2.3.3 of the main text had relegated to the appendix. Let $\Pr(n, l|X, e')$ mark the probability of being reborn into employment state n and skill-loss state l, conditional on having drawn education state e'. Then the value of being reborn is given by

$$\hat{W}(X', 0, a', 0, e, b, s_0) = \beta(e, b) \sum_{s' \in \mathcal{S}_+} \sum_{e'} \sum_{b'} \pi_S(s_0, s') \pi_E(e, e') \pi_b(b') \hat{w}(X', 0, a', 0, e', b', s')$$

with

$$\begin{aligned}\hat{w}(X', 0, a', 0, e', b', s') = \sum_l \Pr(n = 1, l|X, e') \mathbb{E}_\zeta \Big[& [1 - \lambda_x(e') - \lambda_n(e')(1 - f(\widetilde{X}'))] \sum_{\hat{l}} \pi_L^{emp}(l, \hat{l}) W(X', 1, a', \hat{l}, e', b', s') \\ & + [\lambda_x(e') + \lambda_n(e')(1 - f(\widetilde{X}'))] W(X', 0, a', 0, e', b', s') \Big] \\ + \Pr(n = 0|X, e') \mathbb{E}_\zeta \Big[& f(\widetilde{X}') [\pi_L^{uem}(1) W(X', 1, x', 1, e', b', s') + \pi_L^{uem}(0) W(X', 1, x', 0, e', b', s')] \\ & + [1 - f(\widetilde{X}')] W(X', 0, a', 0, e', b', s') \Big].\end{aligned}$$

In order to define the transition probabilities Pr, let $N(X, l, e)$ mark the mass of employed households with earnings-loss state l and education level e, and let $U(X, e)$ mark the mass of households of the same education level that are unemployed.[A1] Then, for any $l \in \{0, 1\}$, $e' \in \{e_L, e_H\}$

$$\Pr(n = 1, l|X, e') := \frac{N(X, l, e')}{\sum_l N(X, l, e') + U(X, e')},$$

and

$$\Pr(n = 0|X, e') := \frac{U(X, e')}{\sum_l N(X, l, e') + U(X, e')}.$$

A.2 The firms' optimization problems

This appendix collects the equations characterizing the solution to the optimization problem of all the firms in the model, after taking first-order conditions, applying envelope conditions, and simplifying. We describe the resulting equations collected under the respective firm's

[A1] $N(X, l, e) = \sum_{s \in \mathcal{S}_+} \int_x d\mu(1, x, l, e, s)$ and $U(X, e) := \sum_{s \in \mathcal{S}_+} \int_x d\mu(0, x, 0, e, s)$.

name. We suppress the dependence on X and $\widetilde{X}$ to keep the notation simple. We follow the same practice in other parts of the appendix whenever clarity allows.

A.2.1 Differentiated goods producers

The problem of the differentiated goods producer is characterized by the following set of equations, in which μ^y is the multiplier on the production function.
First, there is the optimality condition for inflation, where $\Pi = \frac{P}{P_{-1}}$:

$$\psi\Pi\left(\Pi - \bar{\Pi}\right) = \psi\mathbb{E}_{\zeta}\left[Q(X, X')\Pi'\left(\Pi' - \bar{\Pi}\right)y'/y\right] + \left[\vartheta\exp\{\zeta_P\}mc - \left(\vartheta\exp\{\zeta_P\} - 1\right)\right]. \quad (5)$$

The optimality conditions for inputs imply that marginal costs, mc, are given by

$$mc = \left(\frac{1}{\theta}\right)^{\theta}\left(\frac{1}{1-\theta}\right)^{1-\theta}\frac{r^{\theta}h^{1-\theta}}{\zeta_{TFP}}.$$

The optimality conditions for capital and labor services input imply

$$\frac{\theta}{1-\theta}\frac{\ell}{k} = \frac{r}{h}.$$

Finally, there is the production function:

$$y = \zeta_{TFP}\left(k\right)^{\theta}\left(\ell\right)^{1-\theta}.$$

A.2.2 Labor services producers

The problem of employment agencies does not involve any decision beyond the one contained in the free-entry condition. Therefore, the relevant equations are already given in the main text. When solving the model numerically, we make use of its structure to simplify. The only decision of the employment agency that is influenced by the value of various types of matches is the vacancy posting condition. Job-finding and separation rates do not depend on a household's idiosyncratic skills s. Therefore, the share of households of skill s in each education-employment status subgroup follows the constant ergodic distribution of skills. For the free-entry condition, it is, therefore, enough to track the expected value of

J_L with respect to s. Define $\widetilde{J}_L(X,l,e) = \sum_{s\in\mathcal{S}_+} \pi_S(s|s \in \mathcal{S}_+) J_L(X,l,e,s)$. Using that $\sum_{s\in\mathcal{S}_+} \pi_S s(s|s \in \mathcal{S}_+) = 1$ (the calibration assumption that average skills are equal to 1) and using that $\pi_S(s|s \in \mathcal{S}_+)$ is ergodic, we obtain that

$$\begin{aligned}\widetilde{J}_L(X,l,e) \quad = \quad & (1-\tau_d)[h(X)-w(X)]\cdot e(1-\varrho l) \\ & + \textstyle\sum_{l'} \pi_L^{emp}(l,l')\cdot \mathbb{E}_\zeta\big[Q(X,X')\big(1-\lambda_x(e)-\lambda_n(e)\big)\widetilde{J}_L(X,l',e)\big].\end{aligned}$$

With this, one can re-write the free-entry condition as

$$\begin{aligned}&\textstyle\sum_e \sum_l \big[U(\widetilde{X},e)\pi_L^{uemp}(l) + \lambda_n(e) N(\widetilde{X},l,e)\big]\widetilde{J}_L(X,l,e) \\ &\qquad \cdot\big[\textstyle\sum_e [U(\widetilde{X},e) + \lambda_n(e)\sum_l N(\widetilde{X},l,e)]\big]^{-1} = (1-\tau_d)\kappa\left(\frac{M(\widetilde{X},V(\widetilde{X}))/\big(\sum_{l,e} N(\widetilde{X},l,e)\big)}{\overline{M}/\widetilde{\overline{N}}}\right)^2.\end{aligned}$$

A.2.3 Capital services producers

Denoting the Lagrange multiplier on the law of motion for capital by μ_k we obtain three optimality conditions for the producer of capital services . First, there is the intra-temporal condition for utilization:

$$(1-\tau^d)r = \mu_k \delta_1 \delta_2 v^{\delta_2 - 1}.$$

Second, we get an Euler equation for investment:

$$(1-\tau^d) = \mu_k \zeta_I \left[1 - \frac{\phi_K}{2}\left(\frac{i}{i_{-1}}-1\right)^2 - \phi_K\left(\frac{i}{i_{-1}}-1\right)\frac{i}{i_{-1}}\right] + \mathbb{E}_\zeta\left[Q(X,X')\mu_k'\zeta_I'\phi_K\left(\frac{i'}{i}-1\right)(i'/i')^2\right].$$

Third, we get an optimality condition for capital:

$$\mu_k = (1-\tau^d)\mathbb{E}_\zeta\left[Q(X,X')r'v'\right] + \mathbb{E}_\zeta\left[Q(X,X')\mu_k'\big(1-\delta_1(v')^{\delta_2}\big)\right].$$

For completeness we repeat the law of motion for capital:

$$K' = \big(1 - \delta_0 - \delta_1[(v_t)^{\delta_2} - 1]\big)K + \zeta_I \left(1 - \frac{\phi_K}{2}\left(\frac{i}{i_{-1}} - 1\right)^2\right) i.$$

A.3 Goverment budget constraint

The government budget constraint is given by

$$\begin{aligned}
& \textstyle\int_{\mathcal{M}} \mathbb{1}_{s\in\mathcal{S}_+} \mathbb{1}_{n=0}\, b_{UI}(es)\ d\mu + \int_{\mathcal{M}} \mathbb{1}_{s=s_0}\, b_{RET}(e)\ d\mu + g \\
= \quad & \textstyle\tau_d \frac{d_a(X)}{1-\tau_d} + \tau_c \int_{\mathcal{M}} c(X,n,a,l,e,s)\, d\mu \\
& \textstyle + \int_{\mathcal{M}} \mathbb{1}_{s\in\mathcal{S}_+} \mathbb{1}_{n=1}\, (\tau_{UI} + \tau_{RET}) w(X) es(1 - l\varrho)\ d\mu \\
& \textstyle + \int_{\mathcal{M}} \mathbb{1}_{s\in\mathcal{S}_+} \mathbb{1}_{n=1}\, \tau(X, w(X)es(1 - l\varrho))\, [w(X)es(1 - l\varrho)]\ \ d\mu. \\
& \textstyle + \int_{\mathcal{M}} \mathbb{1}_{s\in\mathcal{S}_+} \mathbb{1}_{n=0}\, \tau(X, b_{UI}(es)) b_{UI}(es)\ d\mu. \\
& \textstyle + \int_{\mathcal{M}} \mathbb{1}_{s=s_0}\, \tau(X, b_{RET}(e)) b_{RET}(e)\ d\mu.
\end{aligned}$$

The fiscal authority spends on unemployment and retirement benefits, and government consumption expenditures, g (first line). These expenditures are financed through a tax on dividends ($d_a(X)/(1-\tau_d)$ marks dividends pre-tax) and consumption ($c(X, n, a, l, e, s)$ marks the consumption policy of households), second line. In addition, there are unemployment insurance and social security taxes on earnings (third line), and progressive income taxes on earnings, unemployment benefits, and retirement benefits.

B Definition of equilibrium

This appendix spells out the full definition of a recursive equilibrium in our setting.

Definition (Recursive Equilibrium). A recursive equilibrium is
a set of value functions $W(., n, a, l, e, b, s)$, $J_K(.)$, $J_D(.; j)$, $J_L(., l, e, s)$, a set of private-sector policy functions $c(., n, a, l, e, b, s)$, $a(., n, a, l, e, b, s)$, y, $y_j(.)$, $d_a(.)$, $v(.)$, $i(.)$, $K(.)$, $l_j(.)$, $k_j(.)$, $V(.)$, $P_j(.)$, $y(.)$, a set of prices and discount factors $w(.)$, $p_a(.)$, $h(.)$, $r(.)$, $Q(., .)$, $P(.)$, $\Pi(.)$, a set of labor-market variables $Pr(.|., e)$, $f(.)$, $N(., l, e)$, $U(., e)$, $q(.)$, $N(.)$, $U(.)$, $\kappa(.)$, a set of government policies $\tau(., .)$, $R(.)$, and a set of transition functions $T(.)$, $\widetilde{T}$, such that $X = \widetilde{T}(\widetilde{X})$ and $\widetilde{X}' = T(X)$, for all aggregate states X, $\widetilde{X}$ idiosyncratic states n, a, l, e, b, s, and firm indexes j such that

1. (Households' problems) given asset price $p_a(.)$, dividends $d_a(.)$, wage $w(.)$, job-finding rate $f(.)$, taxes $\tau(., .)$, transition probabilities $Pr(.|., e)$, and transition functions $T(.)$, and $\widetilde{T}(.)$, the value functions $W(., n, a, l, e, b, s)$ solve the households' Bellman equations in Section 2.3, and $c(., n, a, l, e, b, s)$ and $a(., n, a, l, e, b, s)$ are the resulting optimal policy functions for consumption and assets;

2. (Final goods) given $P(.)$ and $P_j(.)$, policy functions $y(.)$ and $y_j(.)$ solve the problem of the final goods producers in Section 2.4.1;

3. (Differentiated goods) given demand function $y_j(.)$, and given prices $r(.)$, $h(.)$, $P(.)$, discount factor $Q(., .)$, and transition functions $T(.)$ and $\widetilde{T}(.)$, $J_D(.; j)$ solves the differentiated goods producers' Bellman equation given in Section 2.4.2, and $k_j(.)$, $l_j(.)$, and $P_j(.)$ are the corresponding optimal policy functions;

4. (Labor services) given prices $h(.)$, wage $w(.)$, discount factor $Q(., .)$, unemployment $U(., e)$, employment $N(., l, e)$ and transition functions $T(.)$, and $\widetilde{T}(.)$, $J_L(., l, e, s)$ solves the employment agencies' valuation equation in Section 2.4.2. ; given $J_L(., l, e, s)$, $U(., e)$, $N(., l, e)$, and $\kappa(.)$, $q(.)$, solves the free-entry condition in the same section; given $M(., .)$ and $q(.)$, $V(.)$ conforms with the definition of the job-filling rate in the

same section; given $M(.,.)$ and $q(.)$, vacancy posting costs $\kappa(.)$ follow the form given in the same section; given $V(.)$, $U(.,e)$, and $N(.,l,e)$, $M(.,V(.))$ is given by the matching function spelled out in the same section; given $V(.)$, $M(.,V(.))$, $U(.,e)$ and $N(.,l,e)$, $f(.)$, the job-finding rate $f(.)$ is as defined in Section 2.4.2.

5. (Capital services) given rental rate $r(.)$, discount factor $Q(.,.)$, and transition functions $T(.)$ and $\widetilde{T}(.)$, $J_K(.,K,i)$ solves the Bellman equation of the representative producer of capital in Section 2.4.2, and $i(.)$, $K(.)$ and $v(.)$ are the resulting optimal policy functions for investment, capital, and utilization, respectively;

6. (Financial firms) given interest rates $R(X)$, inflation $\Pi(X)$, and transition function $T(.)$ and $\widetilde{T}(.)$, the discount factor satisfies the Euler equation in Section 2.5; given final output $y_f(.)$, investment policy $i(.)$, wage $w(.)$, dividends are as described in the same section; for given dividends $d_a(X)$ and the discount factor $Q(.,.)$, the asset price $p_a(.)$ is consistent with the definition of the discount factor in the same section.

7. (Central bank) given inflation $\Pi(.)$ and unemployment $U(.)$, the interest rate $R(.)$ follows the Taylor rule given in Section 2.6.

8. (Fiscal authority) given dividends $d_a(.)$, consumption policies $c(.,n,a,l,e,b,s)$, and wage $w(.)$, $\tau(.,.)$ balances the government budget in every period (Section 2.6);.

9. (Wage) given $y(.)$, the wage follows the wage rule spelled out in Section 2.4.2;

10. (Birth) $Pr(.|.,e)$ is consistent with the flows into retirement and new birth described in Section 2.3.3;

11. (Consistency, demand function) $y_j(.) = y_{f,j}(.) + y_{a,j}(.)$ is the demand for good j.

12. (Symmetry) for all j, $P_j(.) = P(.)$, $y_j(.) = y(.)$, and $y_j(.) = y(.)$.

13. (Market clearing, goods)

$$y(.) = \int_{\mathcal{M}} c(.,n,a,l,e,b,s)d\mu(.) + i(.) + g + \frac{\psi}{2}\left(\Pi(.) - \bar{\Pi}\right)^2 y(.) + \kappa\left(\frac{M(.)/\left(\sum_{l,e} N(.,l,e)\right)}{\overline{M}/\widetilde{\overline{N}}}\right)^2 M(.) + \Xi;$$

14. (Market clearing, capital) $\int_0^1 k_j(.)dj = K_{-1}(.)v(.)$;

15. (Market clearing, labor services) $\int_{\mathcal{M}} se(1-\varrho l)1_{n=1} d\mu = \int_0^1 l_j dj$;

16. (Market clearing, shares) $\int_{\mathcal{M}} a(X,n,a,l,e,s) d\mu = 1$;

17. (Consistency, capital flow)

$$K(.) = [1-\delta_0 - \delta_1(v(.)^{\delta_2}-1)]\cdot K_{-1}(.) + \zeta_I[1-\phi_K/2\left(\frac{i(.)}{i_{-1}(.)}-1\right)^2]i(.)$$

18. (Consistency, employment flow) Employment flows have to be consistent with the evolution of μ and $\widetilde{\mu}$ and the respective definition of the employment aggregates, $N, N(.,l,e)$, $U(.,e)$, U.

19. (Consistency, aggregate state transition) $T, \widetilde{T}$ are consistent with $K_{-1}(T(X)) = K(X)$, $w_{-1}(T(X)) = w(X)$, $i_{-1}(T(X)) = i(X)$, $R_{-1}(T(X)) = R(X)$ and $K_{-1}(\widetilde{T}(\widetilde{X})) = K_{-1}(\widetilde{X})$, $w_{-1}(\widetilde{T}(\widetilde{X})) = w_{-1}(\widetilde{X})$, $i_{-1}(\widetilde{T}(\widetilde{X})) = i_{-1}(\widetilde{X})$, $R_{-1}(\widetilde{T}(\widetilde{X})) = R_{-1}(\widetilde{X})$.

20. $T, \widetilde{T}$ are consistent with the law of motion for the distribution (described in Section B.1).

B.1 Law of motion of distributions μ, $\widetilde{\mu}$

It remains to state the law of motion for μ and $\widetilde{\mu}$. Let A be a measurable subset of $\mathbb{R}_+$, the set of feasible asset holdings. We need to describe the updating of $\widetilde{\mu}$ to μ and of μ to $\widetilde{\mu}'$ for all feasible combinations of (n, A, l, e, b, s).

B.1.1 Transitions from $\widetilde{\mu}$ to μ

We start with the transition from $\widetilde{\mu}$ to μ, that is from the beginning of the period (after shocks to the exogenous idiosyncratic states (e, b, s) and the aggregate states have been realized, but before employment transitions of working-age households have occurred and before earnings-loss transitions have materialized) to the end of the period (the production stage).

The retired can neither lose nor find a job, and the earnings-loss state does not matter for their income. Therefore, for $s = s_0$ we have $\mu(n, A, l, e, b, s_0) = \widetilde{\mu}(n, A, l, e, b, s_0)$. For $s \in \mathcal{S}_+$

(working-age households, including those that have just been reborn), we have for $n = 1$ at the production stage

$$\begin{aligned} \mu(1, A, l, e, b, s) &= \sum_{\hat{l}\in\{0,1\}} \big(1 - \lambda_x(e) - \lambda_n(e)(1 - f(\widetilde{X}))\big)\pi_L^{emp}(\hat{l}, l)\widetilde{\mu}(1, A, \hat{l}, e, b, s) \\ &\quad + \sum_{\hat{l}\in\{0,1\}} f(\widetilde{X})\pi_L^{uem}(l)\widetilde{\mu}(0, A, 0, e, b, s), \end{aligned}$$

and for $n = 0$ at the production stage

$$\begin{aligned} \mu(0, A, 0, e, b, s) &= \sum_{\hat{l}\in\{0,1\}} \big(\lambda_x(e) + \lambda_n(e)(1 - f(\widetilde{X}))\big)\widetilde{\mu}(1, A, \hat{l}, e, b, s) \\ &\quad + \big(1 - f(\widetilde{X})\big)\widetilde{\mu}(0, A, 0, e, b, s). \end{aligned}$$

B.1.2 Transitions from μ to $\widetilde{\mu}'$

We now turn to the transition from μ to $\widetilde{\mu}'$. We start with households that end up in the labor force next period. For $s \in \mathcal{S}_+$, we have

$$\begin{aligned} \widetilde{\mu}'(n, A, l, e, b, s) &= \textstyle\sum_{\hat{s}\in\mathcal{S}_+} \pi_S(\hat{s}, s) \int_{\hat{a}:a(X,1,\hat{a},l,e,b,\hat{s})\in A} d\mu(X, n, \hat{a}, l, e, b, \hat{s}) \\ &\quad + \pi_S(s_0, s)\Pr(n, l|X, e) \textstyle\sum_{\hat{e}} \sum_{\hat{b}} \pi_E(\hat{e}, e)\pi_{\Delta\beta}(b) \\ &\qquad \cdot \int_{\hat{a}:a(X,0,\hat{a},l,\hat{e},\hat{b},0)\in A} d\mu(X, 0, \hat{a}, l, \hat{e}, \hat{b}, 0). \end{aligned}$$

For transitions into old age, the following rule applies:

$$\begin{aligned} \widetilde{\mu}(\widetilde{X}', 0, A, 0, e, b, s_0)' &= \textstyle\sum_l \sum_n \sum_{\hat{s}\in\mathcal{S}_+} \pi_S(\hat{s}, s_0) \\ &\qquad \cdot \int_{\hat{a}:a(X,n,\hat{a},l,e,b,\hat{s})\in A} d\mu(X, n, \hat{a}, l, e, b, \hat{s}) \\ &\quad + \pi_S(s_0, s_0) \int_{\hat{a}:a(X,0,\hat{a},0,e,b,s_0)\in A} d\mu(X, 0, \hat{a}, 0, e, b, s_0). \end{aligned}$$

C Solution algorithm

This appendix outlines our solution algorithm. We extend the perturbation method developed by Reiter (2009) and Reiter (2010a) to compute a second-order approximation with a parameterized law of motion for the distribution of households.[C2] The parameterized law of motion is obtained from a principal-component decomposition of the first-order dynamics of the distribution of wealth. This step is necessary as, on the one hand, a full second-order solution is infeasible given currently available RAM and the size of the model, and, on the other hand, we need to compute a second-order solution to study welfare along the business-cycle dimension.[C3]

We use splines to approximate households' decision rules along their asset dimension, and approximate the distribution of households as a histogram on the product of skill state, discount factor, education, employment state and a not-equally spaced grid with more points close to the borrowing constraint on the wealth distribution. The solution algorithm takes the following steps:

1. Solve for the model's steady state without aggregates shocks. Collect the values of aggregate variables, the households' decision rules, value functions,[C4] and distributions on their respective grids.

2. Collect all equations characterizing the solution of the model economy. Take first derivatives of these equations with respect to aggregate variables, households' policy functions on the grids, and the mass of agents in each bin of the approximated histogram at the steady state.[C5] Solve for the first-order policy and transition matrices

[C2]See also Winberry (2018), Ahn et al. (2017), and Bayer and Luetticke (2020) for closely related solution strategies.

[C3]In earlier versions of the paper we used an approach closer to Krusell and Smith (1998), in which we forecasted the expectation terms in the firms' Euler equations and asset prices, and later a method based on Reiter (2010b). While these methods allow for a global solution of the model, they suffer from a strong curse of dimensionality, limiting the number of aggregate states one can take into account. The algorithm described here overcomes this constraint.

[C4]In practice, we approximate the expected marginal utility of the households and the value function at the beginning of the period before idiosyncratic uncertainty for the period is resolved. This makes it easier to deal with the borrowing constraint when we apply some of the dimension reductions discussed below. The beginning-of-period value function is the object used in the calculation of the welfare effects of policy changes so we approximate it directly.

[C5]In practice, it helps to drop one of the bins from the set of histograms and to use the fact that the total mass has to be 1. In addition, we are keeping track of the aggregate mass of agents in employment using the algorithm described in Schmitt-Grohé and Uribe (2004).

3. Use the first-order solution to compute the variance-covariance matrix of the deviations of the distribution of assets (the mass points in the respective bins of the histogram) from the steady state. Compute a principal-component decomposition of the matrix. Keep the first n principal-component vectors so that these n components explain x percent of the total variation of the distribution, for example, 99.9 percent, based on the principal-component analysis. Use the principal-component vectors to compute two projection matrices: one, D, from $\mathbb{R}^n$ into the linear space spanned by the principal-component vectors, and the other, H, which projects back from this space onto $\mathbb{R}^n$, such that $D \cdot H$ equals the identity matrix in $\mathbb{R}^n$.[C6]

4. Collect all equations characterizing the solution of the model economy again. To reduce the number of state variables we now use the sum of the distribution in the steady state, μ^{SS}, and $D \cdot p$ in place of tracking the mass of agents in each bin of the approximated histogram at each point in time separately. Here p is a vector in $\mathbb{R}^n$ weighting the different principal components. Its changes over time to allow us to track, approximately, changes in the distribution.[C7] In practice, in our system of equations, the economy starts the period with a vector p as part of the state. We then assume $\mu^{ss} + D \cdot p$ as the beginning-of-period distribution, use it in all equations involving the distribution and update it using the law of motion for the distribution. Finally, we subtract μ^{ss} from the resulting end-of-period distribution and project the difference on H to obtain p', as part of the new state vector. Add these adjustments to the model equations. Take first and second derivatives of these equations with respect to aggregate variables, households' policy and value functions on the grids,

with and without skill loss by education, and use this to reduce the number of bins to track further. Here, we are utilizing the fact that the shares of agents in different skill and discount factor states are constant over time and that the job-finding and -loss rate does not depend on these characteristics.

[C6]This procedure follows Reiter (2010a). More details and motivation can be found there. In practice, we found that adding the asset price relative to the steady state as another variable in the decomposition increased both numerical efficiency and stability as it directly relates to the dynamics of the stochastic discount factor as well as total wealth in our setting.

[C7]Given the derivation of H and D we expect the approximate dynamics to be fairly close to the full ones, and indeed, we verified that the first-order dynamics for aggregate variables of the model with and without this reduction in the state space are extremely close. We can think of $D \cdot p$ as describing the most likely state of the distribution if a projection of the histogram using H results in p.

and the new state variables just introduced at the steady state. Solve for the first- and second-order policy and transition matrices.

To reduce the computational complexity of the problem further, we follow Ahn et al. (2017) and Bayer and Luetticke (2020) and approximate the deviations of households' policy and value functions from the steady state using a piece-wise linear spline of a smaller order than the grid used to solve for steady-state policy functions. We verified that increasing the degree of the spline and the number of principal components did not change our conclusions.[C8] We implement the algorithm in MATLAB using a modified version of the codes provided with Schmitt-Grohé and Uribe (2004). We adjust them to allow us to handle the very large derivative matrices resulting from the second-order approximation. We need around $300GB$ of RAM to perform the calculations; this is so despite making use of the sparsity of the matrices and the reduction in the number of policy functions. We use a spline of order thirteen, and four principal components for the results in the text and have verified that both the model dynamics and other implications are robust to changes in these numbers.

[C8] We also experimented with Chebyshev polynomials and a smoother spline. In the end, all methods gave similar answers and we used the piece-wise linear spline as it gave us the best trade-off between precision and number of parameters to approximate.

D Further information on the calibration, model fit

This appendix provides further details on the calibration and on how well the model fits the data. Appendix D.1 provides the summary tables for the calibration of Section 3 in the main text.

D.1 Summary tables on calibration

This appendix provides a summary of the calibrated parameters of the model. This serves to collect the parameters. Section 3 of the main text provides a detailed discussion.

D.1.1 Summary tables for Section 3.1: preferences, education, earnings loss

Table D1: Preferences, education, and earnings losses — Targets and parameterization

Parameter	Value	Target
Preferences		
σ	2.5	Blundell et al. (2016).
$\pi_b(0)$	0.50	Equal mass of patient and impatient.
β_{e_L}	0.974	Low-educated hold 30% of aggregate net worth, SCF.
β_{e_H}	0.985	Real rate of interest of 3.05% p.a.
Δ_β	0.110	Wealth share poorest 20% of working-age, SCF.
γ_1	18,854	Wealth share of the poorest 50% of retirees, SCF.
γ_2	6.1	Minimize distance wealth Lorenz curve working-age, SCF.
Education		
e_L	1	Normalized to unity.
e_H	1.5	College wage premium, Mukoyama and Sahin (2006).
$\pi_E(e_L, e_L)$	0.8	Share of low-educated, SCF.
$\pi_E(e_H, e_H)$	0.7	Intergen. elasticity of income of 0.5.
Earnings losses		
ϱ	0.25	Initial loss, Couch/Placzek (2010), Altonji *et al.* (2013)
$\pi_L^{emp}(1,0)$	0.025	Loss of 14% after six years, Couch/Placzek (2010).
$\pi_L^{emp}(0,1)$	0	Cannot acquire earnings loss while employed.
$\pi_L^{uem}(1)$	0.975	$\pi_L^{uem}(1) = 1 - \pi_L^{emp}(1,0)$.

Notes: Calibrated parameters for preferences, education, and earnings losses. The main text provides further details.

D.1.2 Summary tables for Section 3.1: calibration of skills

Table D2 provides the targets for calibrating the skills and lists how many restrictions each target delivers. See page 21 of the main text for a detailed discussion of these targets.

Table D2: Skill distribution — Targets

	Targets	# restrictions
Assumptions on skill levels		
(i)	Average length of a working life: 40 years	1
(ii)	Average length of retirement: 12 years	1
(iii)	Length of working life independent of skill level	2
(iv)	Skills after birth according to ergodic distribution	2
(v)	Ergodic mass super-skilled in working-age pop. 1%	1
(vi)	Prob. remain super-skilled if not retiring 0.975	1
(vii)	Probability of becoming s_3 independent of s_1 and s_2	1
(viii)	Ergodic distrib. determines transition from s_3 to s_1, s_2	1
(ix)	Equal ergodic mass of low- and medium-skill agents	1
(x)	Persistence of residual earnings of 0.975	1
(xi)	Ergodic standard deviation of residual earnings of 0.51	1
(xii)	Normalize average skill of workers to 1	1
(xiii)	Normalize $s_0 = 0$ (no labor income in retirement)	1
(xiv)	Target 0.825 for the Gini index of wealth of the working aged	1

Notes: Calibration strategy for skills. Section 3.1 of the main text provides further details.

Table D3: Skill distribution — Parameterization

		Transition probabilities, $\pi_S(s, s')$			
	Level	s'_0	s'_1	s'_2	s'_3
s_0	0	0.9792	0.0103	0.0103	0.0002
s_1	0.488	0.0063	0.9814	0.0121	0.0003
s_2	1.298	0.0063	0.0121	0.9814	0.0003
s_3	11.600	0.0063	0.0124	0.0124	0.9689

Notes: Levels of idiosyncratic productivity (left), transition probabilities of skills per quarter (right). s_0 : retirement, s_1 : lowest skill group, s_3 : highest skill group. Rounding means that rows may not sum to 1.

D.1.3 Summary tables for Section 3.2: firms and production

Table D4: Production sector—
Targets and parameterization

Parameter	Value	Target
Capital services		
δ_0	0.015	depreciation rate of 1.5% per quarter, NIPA.
δ_1	0.0169	unitary utilization in steady state.
δ_2	1.33	Comin and Gertler (2006).
ϕ_K	10	mid-point of estimates in Christiano et al. (2016).
Labor services		
ϕ_w	0.837	Barattieri et al. (2014) for job stayers.
$\lambda_x(e_L)$	0.048	70.1% of separations for e_L exogenous; see text.
$\lambda_x(e_H)$	0.019	65.3% of separations for e_H exogenous; see text.
$\lambda_n(e_L)$	0.114	rel. unempl. rate e_H and e_L as in Table E11.
$\lambda_n(e_H)$	0.056	economy-wide average unempl. rate of 6%; sample average.
$\overline{w}$	0.898	st.-st. job-finding rate, $f = 0.82$.
α	2.63	st.-st. job-filling rate $q = 0.71$, den Haan et al. (2000).
κ	0.33	hire cost 50% of qtrly wage, Silva and Toledo (2009).
Differentiated goods		
ψ	179.4	slope of Phillips curve as in Galí and Gertler (1999).
θ	0.284	investment-GDP ratio of 0.18.
ϑ	6	20% markup.
Ξ	0.125	labor-income share of 0.66.
Implied steady-state values used as parameters		
$\overline{y}$	1.16	implied steady-state level of production y.
$\overline{M}$	0.091	implied steady-state value of matches M.
$\overline{\widetilde{N}}$	0.723	implied steady-state value of employment, $N(\widetilde{X})$.
$\overline{N}$	0.723	implied steady-state value of employment, N.

Notes: Calibration for capital services, labor services, differentiated goods, and parameters that are related to steady-state values. The main text provides further details.

D.1.4 Summary tables for Section 3.3: central bank and fiscal policy

**Table D5: Central bank and fiscal authority—
Targets and parameterization**

Parameter	Value	Target
Central bank		
ϕ_R	0.8	Christiano et al. (2016).
ϕ_Π	1.5	Taylor (1993)
ϕ_u	0.15	Taylor (1993).
$\overline{\Pi}$	1.005	inflation target 2% p.a.
$\overline{U}$	0.0462	steady-state level of unemployment rate of 6%.
$\overline{R}$	1.013	in line with annual real rate of 3.2% p.a.
Fiscal authority – expenditures		
g	0.19	NIPA, share of government spending in GDP.
$\bar{b}_{UI}$	0.5	based in Graves (2020); see text.
$b_{RET}(e_L)$	0.32	Huggett and Parra (2010).
$b_{RET}(e_H)$	0.46	Huggett and Parra (2010).
Fiscal authority – revenues		
$\tau_{RET} \cdot 100$	13.2	balances social security system in steady state.
$\tau_{UI} \cdot 100$	1.5	balances UI system in steady state.
$\tau_c \cdot 100$	7	NIPA, as in Fernández-Villaverde et al. (2015).
$\tau_d \cdot 100$	36	NIPA, as in Fernández-Villaverde et al. (2015).
τ_0	0.182	Guner et al. (2014).
τ_1	3.044	Guner et al. (2014).
τ_2	1.496	Guner et al. (2014).

Notes: The table shows the calibrated parameters for the monetary and fiscal authority. The main text explains the calibration targets.

D.2 List of targeted moments

This appendix lists the data moments that were targeted during the calibration of the model's steady state and the resulting values in the steady state of the model.[D9] As per the fit of the wealth distribution, see Appendix D.3.

[D9] We omit targets in cases where we simply set a parameter to match values found in previous research from this appendix. An example of such a parameter is relative risk aversion, which we target to be 2.5 based on Blundell et al. (2016). The same goes for parameters we found through the maximum likelihood estimation of the RANK version of the model.

Table D6: Moments matched exactly

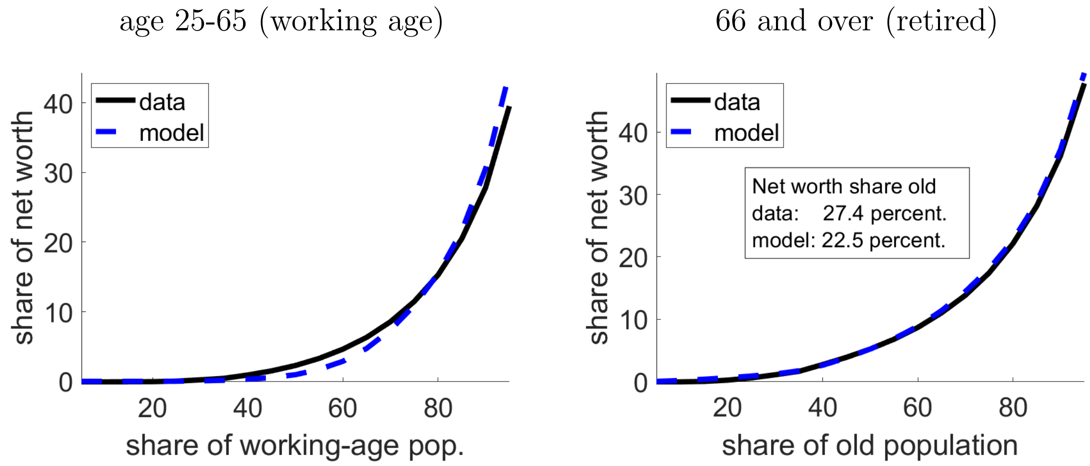
Target Description	Target	Model	Source
Post-Tax Real Rate	3.05%	3.05%	SCF.
Wealth Share Low-educated	30%	30%	SCF.
Wealth Share Poorest 20% Workers	0%	0%	SCF.
Wealth Share Poorest 50% retired	5.25%	5.25%	SCF.
Average Working Life	40 years	40 years	Sample choice.
Average Retirement Length	12 years	12 years	SCF.
Share Low Educated Worker	60%	60%	SCF.
Intergen. Elasticity of Income	0.5	0.5	Solon (1992), Mazumder (2005).
Initial earnings loss	25%	25%	Couch/Placzek (2010), Altonji *et al.* (2013).
Loss six years later	14%	14%	Couch and Placzek (2010).
Stand. Dev. Residual Earnings	0.508	0.508	Floden and Lindé (2001).
Wealth Gini Working Age	82.5	82.5	SCF.
College Wage Premium	50%	50%	Mukoyama and Sahin (2006).
Capital Depreciation Rate	1.5%	1.5%	NIPA.
Utilization	1	1	Normalization.
Unemployment Rate	6%	6%	BLS.
$\frac{\text{Total Cost per hire}}{\text{Average Wage}}$	50%	50%	Silva and Toledo (2009).
Job-Finding Rate	0.82	0.82	CPS.
Job-Filling Rate	0.71	0.71	den Haan et al. (2000).
Labor Share	66%	66%	NIPA.
$\frac{\text{Investment}}{\text{GDP}}$	18%	18%	NIPA.
Inflation Rate	2% p.a.	2% p.a.	Inflation target.
$\frac{\text{Government Spending}}{\text{GDP}}$	19%	19%	NIPA.

Notes: 'Target Description' explains what moment was target. 'Target' provides the targeted value. 'Model ' lists the corresponding value from the calibrated steady state of the HANK model. 'Source' adds information on the source of 'Target Value.' This table contains moments that were, by design, matched exactly.

D.3 Wealth distribution

Figure D1 plots the Lorenz curves for net worth from the model, for working-age households and households of retirement age. Note that the wealth Lorenz curves were a target in the

Figure D1: Model vs. data. Wealth distribution



Notes: Wealth Lorenz curves within each age group. Comparing model (blue dashed line) and data (solid line). Left: working age (25-65). Right: old age (66 and over).

calibration. The model matches these well. The share of aggregate net worth held by the old is 27.4 percent in the data. In the model, the retired households hold 22.5 percent of aggregate wealth. Note that this moment was not targeted by our calibration.

D.4 Households' sources of income

This appendix first documents that U.S. households' sources of income differ starkly by net worth and age. Then, the appendix shows that this patterns is also borne out by the model. Table D7 reports the share of income derived from different sources, by age and percentiles of net worth. All data are from the 2004 Survey of Consumer Finances (SCF), the last wave before the end of our calibration sample. The first block reports sources of income and wealth for what we define as working-age households (household heads aged 25-65 with no social security income).

Table D7: Data. Income sources by net worth (percent of total income)

	Percentile of net worth						
ages 25-65	0-20	20-40	40-60	60-80	80-95	Top 5	Top 1
Labor income	90.4	93.2	90.0	86.5	76.5	58.3	51.6
Financial income	1.2	3.5	8.0	12.1	23.0	40.6	47.6
Transfers	8.4	3.3	2.1	1.5	0.5	0.9	0.8
ages 66-99	0-20	20-40	40-60	60-80	80-95	Top 5	Top 1
Financial income	2.8	6.8	22.8	33.5	50.5	78.5	89.1
Transfers	97.2	93.2	77.2	66.5	49.5	21.5	10.9

Notes: Based on SCF 2004. Households with heads ages 25 to 65 and households with heads ages 66 to 99. All entries in percent. Share of annual income coming from labor income, financial income, social security, and transfers other than social security (such as unemployment benefits). For the block with households ages 25-65, we exclude households receiving social security income. For this age group transfers reported here are transfers other than social security. For the block with households ages 66-99, the measure of annual income excludes labor income. Transfers are the sum of social security and other transfers. For the exact definitions, see the text in Appendix E.1.

The table splits income into three sources: labor income (including a share of 60 percent of the income derived from actively managed businesses), financial income (including imputed income from housing and retirement savings), and transfers (transfers other than social security income, since we exclude working-age households that draw social security income). Labor income is the dominant source of income for all but the wealth-richest working-age households.

The second block of the table reports sources of income and wealth for what we define as old households (defined as households whose head is 66 years of age or older). In keeping with our modeling, the composition of income for the retired focuses only on financial income and transfers (the shares of income reported exclude any remaining labor income). Transfers (primarily social security) are the dominant source of income for the wealth-poorest households of retirement age. For the wealth-richest 5 percent of older households, financial income accounts for 78 percent of income. Importantly, financial income is an important source of income even the median net-worth old household, which financial income accounts for roughly a quarter of income. Older households, thus, are more exposed to changes in financial income than households of working age.

Table D8 provides the model-based counterpart to Table D7. The calibrated model matches the overall pattern of the shape of the distribution of incomes. For the working-age households, the fit is very close, with, perhaps, the exception of the share of income derived from financial sources for the top 1 percent of incomes, which our model overstates.

Table D8: Model. Income sources by net worth (percent of total income)

	Percentile of net worth						
working age	0-20	20-40	40-60	60-80	80-95	Top 5	Top 1
Labor income	96.5	97.0	96.6	87.7	79.3	58.5	33.2
Financial income	0.0	0.3	1.9	10.3	19.7	41.2	66.6
Transfers	3.5	2.7	1.5	2.0	1.0	0.3	0.2
retired							
Financial income	1.3	3.6	9.6	21.6	36.8	76.3	91.2
Social security	98.7	96.4	90.4	78.4	63.2	23.7	8.8

Notes: Based on the model calibrated in Section 3. For the respective statistics in the data, see Table D7 in Section 3.

For the retired, too, the model matches the gradient of income share by net worth. Comparable to the data, the top 5 percent of old households by net worth draw roughly three quarters of their income from financial sources. For the remaining old households, too, the calibration correctly reflects that financial income is an important source of income. At the same time, the calibration somewhat underestimates financial income's importance: Where in the data, the median net-worth old household draws about 23 percent of income from financial sources, in the model the same group of households only draws roughly 7 percent of income from the same source.

D.5 Second moments

For comparing the fit of the model with the business-cycle facts, we rely on the data described in Appendix E.3. We start with the series that cover the period 1977Q1 to 2015Q4. After

HP-filtering (HP-weight 1600), so as to avoid the HP-filter's end-point problem, we drop observations at the beginning and end to arrive at a sample of HP-filtered observations covering the period 1984Q1 to 2008Q3. Table D9 presents the corresponding moments and compares them to the moments in the model.

Table D9: Model vs. Data – Filtered Second Moments

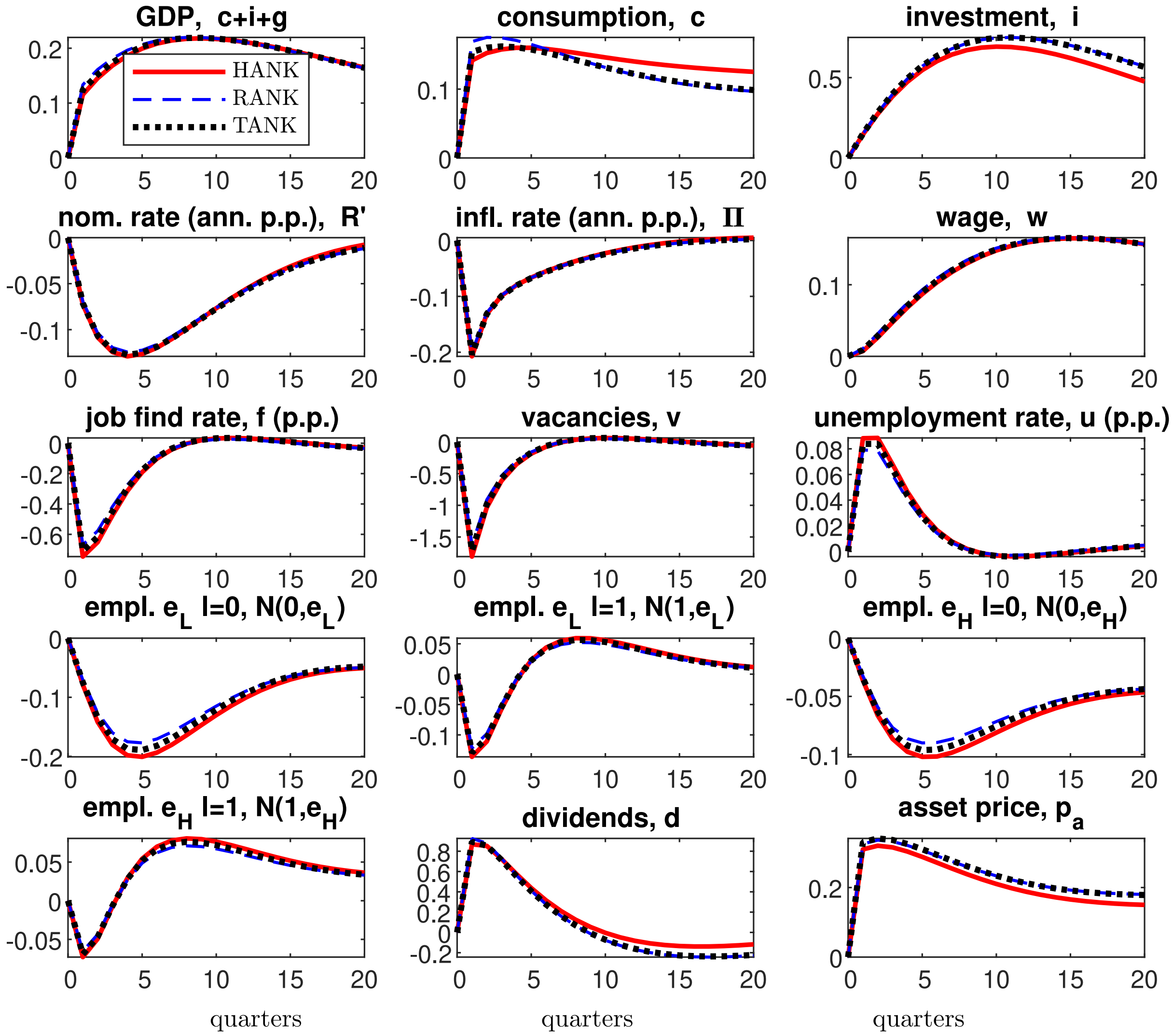
	Model									Data		
	heterog. hh.			TANK			RANK			1984Q1-2008Q3		
	Std	Corr	AR1	Std	Corr	AR1	Std	Corr	AR1	Std	Corr	AR1
<u>Output</u>												
GDP, $c+i+g$	0.93	1.00	0.69	0.88	1.00	0.70	0.86	1.00	0.69	1.06	1.00	0.90
Consumption, c	0.59	0.60	0.67	0.46	0.52	0.68	0.46	0.44	0.66	0.90	0.88	0.87
Investment, i	4.24	0.92	0.69	4.26	0.94	0.69	4.29	0.94	0.70	5.05	0.90	0.89
Capacity util., v	2.23	0.61	0.22	2.11	0.59	0.22	2.05	0.58	0.21	2.21	0.80	0.93
<u>Labor market</u>												
Unempl. rate (e_L)	0.83	-0.80	0.77	0.78	-0.78	0.77	0.77	-0.76	0.77	0.63	-0.84	0.97
Unempl. rate (e_H)	0.41	-0.80	0.78	0.39	-0.77	0.79	0.38	-0.76	0.78	0.33	-0.82	0.97
Employment	0.70	0.80	0.77	0.67	0.78	0.78	0.65	0.76	0.77	0.57	0.84	0.97
Flow rate $U \to E$ $f(X)$	5.07	0.80	0.73	4.81	0.78	0.73	4.70	0.76	0.73	4.07	0.83	0.97
Flow rate $E \to U$ e_L	0.48	-0.80	0.73	0.45	-0.77	0.74	0.44	-0.76	0.73	0.31	-0.88	0.96
Flow rate $E \to U$ e_H	0.24	-0.80	0.73	0.22	-0.77	0.73	0.22	-0.76	0.73	0.15	-0.77	0.93
Vacancies, V	10.26	0.73	0.55	9.64	0.71	0.55	9.45	0.70	0.55	11.18	0.86	0.93
<u>Prices</u>												
Wage, W	1.03	0.23	0.70	0.92	0.21	0.66	0.92	0.19	0.66	0.86	0.34	0.78
Inflation, Π [1]	0.77	0.22	0.56	0.76	0.19	0.56	0.75	0.17	0.56	0.62	0.31	0.43
Nominal rate, R [1]	0.94	-0.25	0.65	0.96	-0.19	0.65	0.95	-0.21	0.65	1.24	0.65	0.92

Notes: The table compares moments of the data and two variants of the model (heterogeneous households, representative households). The model moments follow the construction of the data. They are based on 100 repeated simulations of the model. Each simulation is initialized with 500 periods of simulations that are dropped for the computation of the moments. The next 156 periods are kept. In each case, we take the natural log of the data and compute the cyclical component of the data multiplied by 100 so as to have percentage deviations from trend. The trend is an H-P-trend with weight 1,600. We then drop the first 28 and last 29 observations and compute moments of interest. Finally, we average across the simulations. The left block shows the model's moments, the block on the right the datas'. The first column ("Std.") reports the standard deviation of each series. The second column ("Corr") shows the correlation of the series with GDP. The final column ("AR1") shows the autocorrelation of the series. [1]: the nominal interest rate and inflation are reported in annualized percentage points.

The calibration replicates the fluctuations that we observe in the data rather well. Relative to both RANK and TANK, the HANK economy shows somewhat amplified business cycles owing to the larger volatility of consumption in the HANK model.

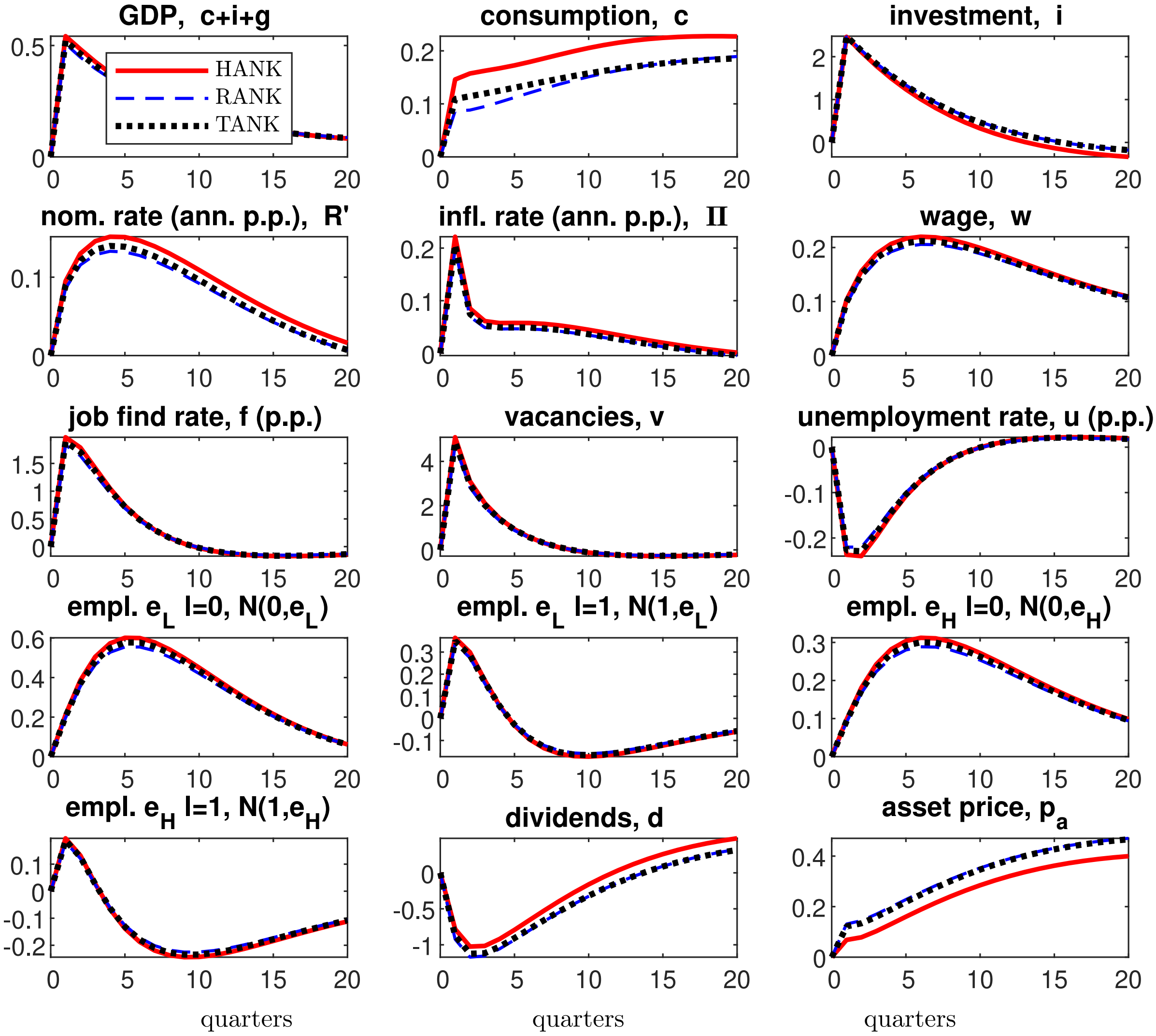
D.6 Impulse responses, aggregate variables

Figure D2: Impulse response to TFP shock, ζ_{TFP}



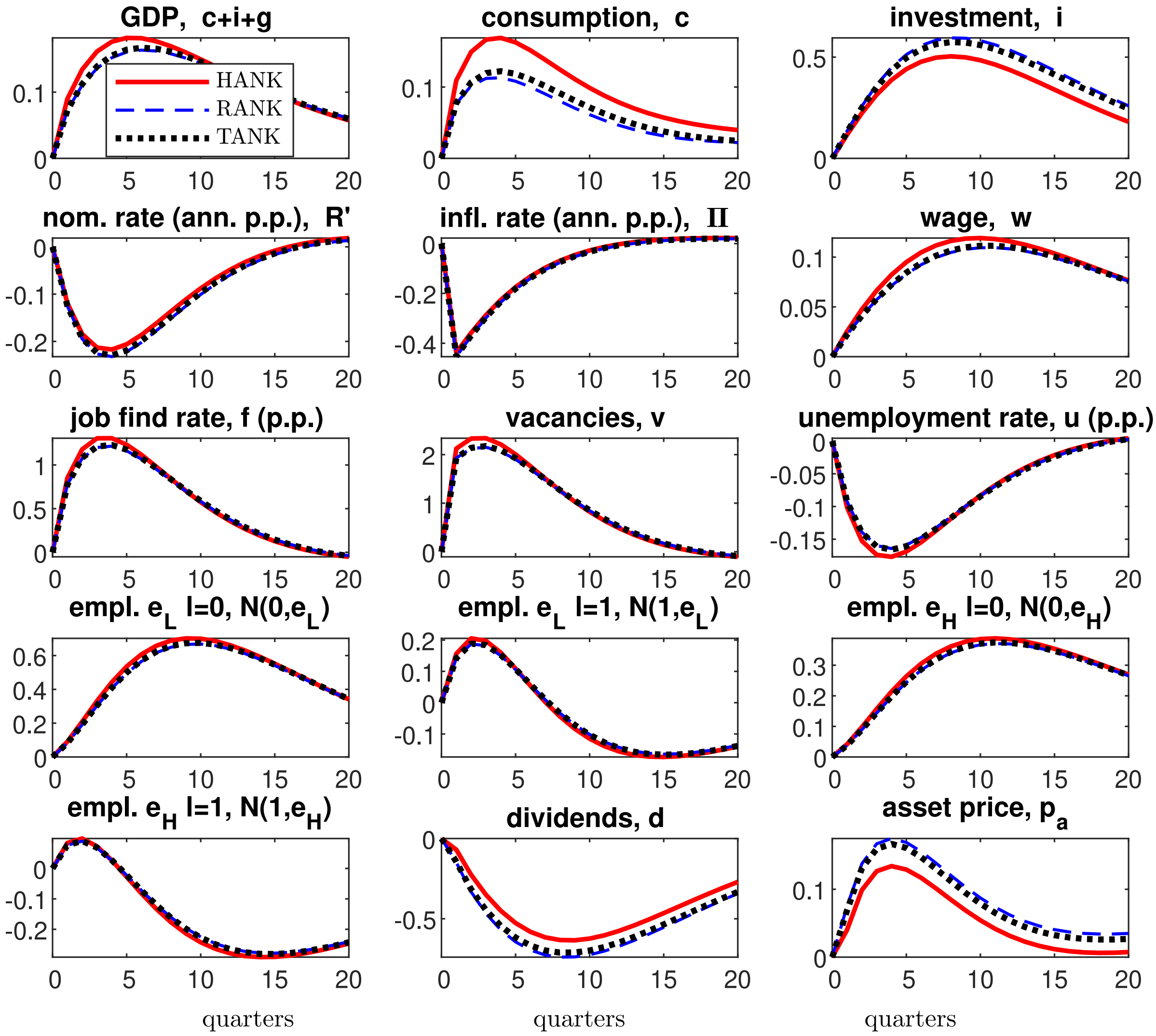
Notes: Impulse response to a one-standard-deviation TFP shock, starting at the stochastic steady state. All variables expressed as percent deviations, unless noted otherwise. ann. p.p.: expressed in annualized percentage points. p.p.: expressed in percentage points.

Figure D3: Impulse response to MEI shock, ζ_I



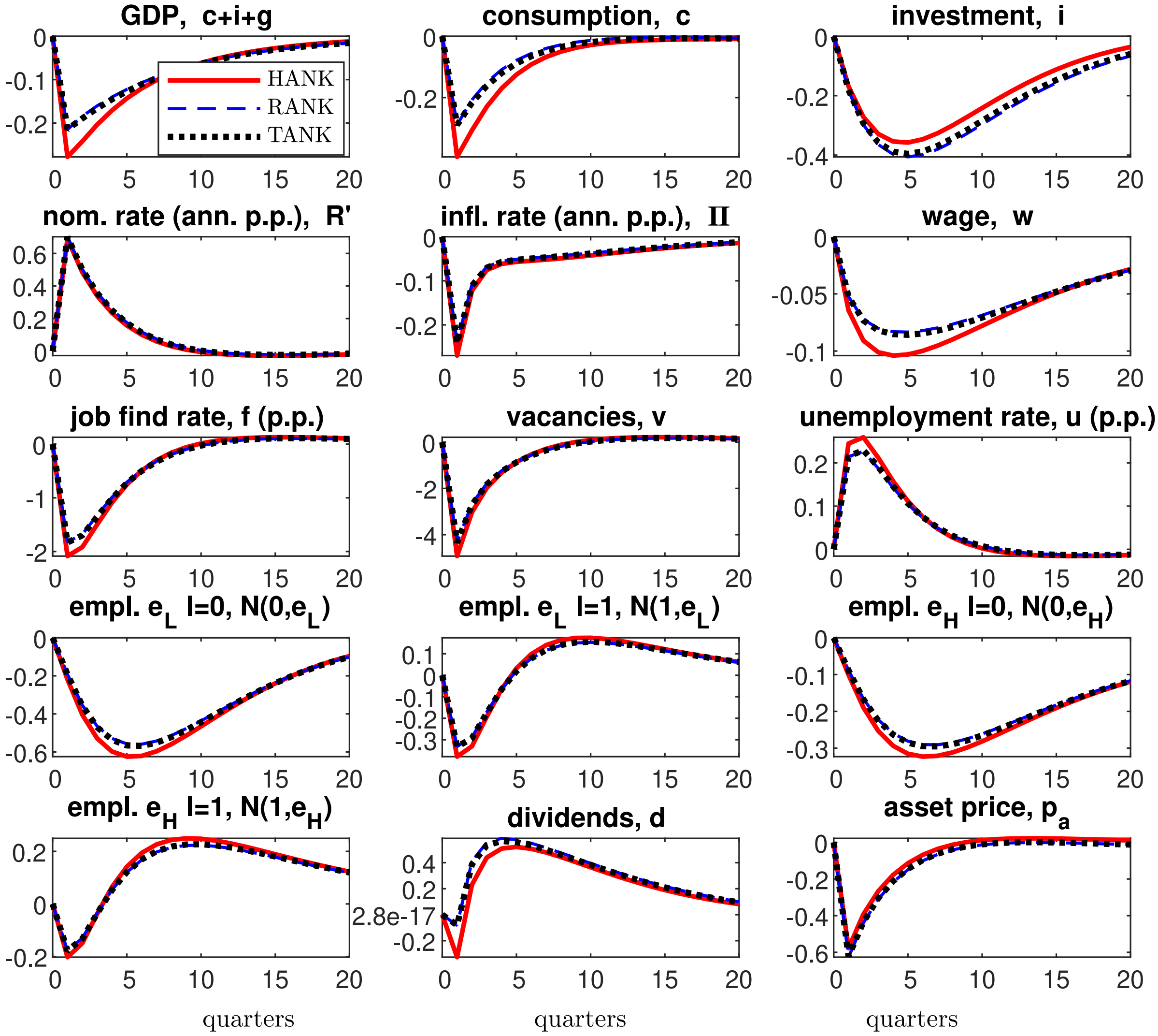
Notes: Impulse response to a one-standard-deviation MEI shock, starting at the stochastic steady state. All variables expressed as percent deviations, unless noted otherwise. ann. p.p.: expressed in annualized percentage points. p.p.: expressed in percentage points.

Figure D4: Impulse response to demand-elasticity shock (a negative price-markup shock), ζ_P



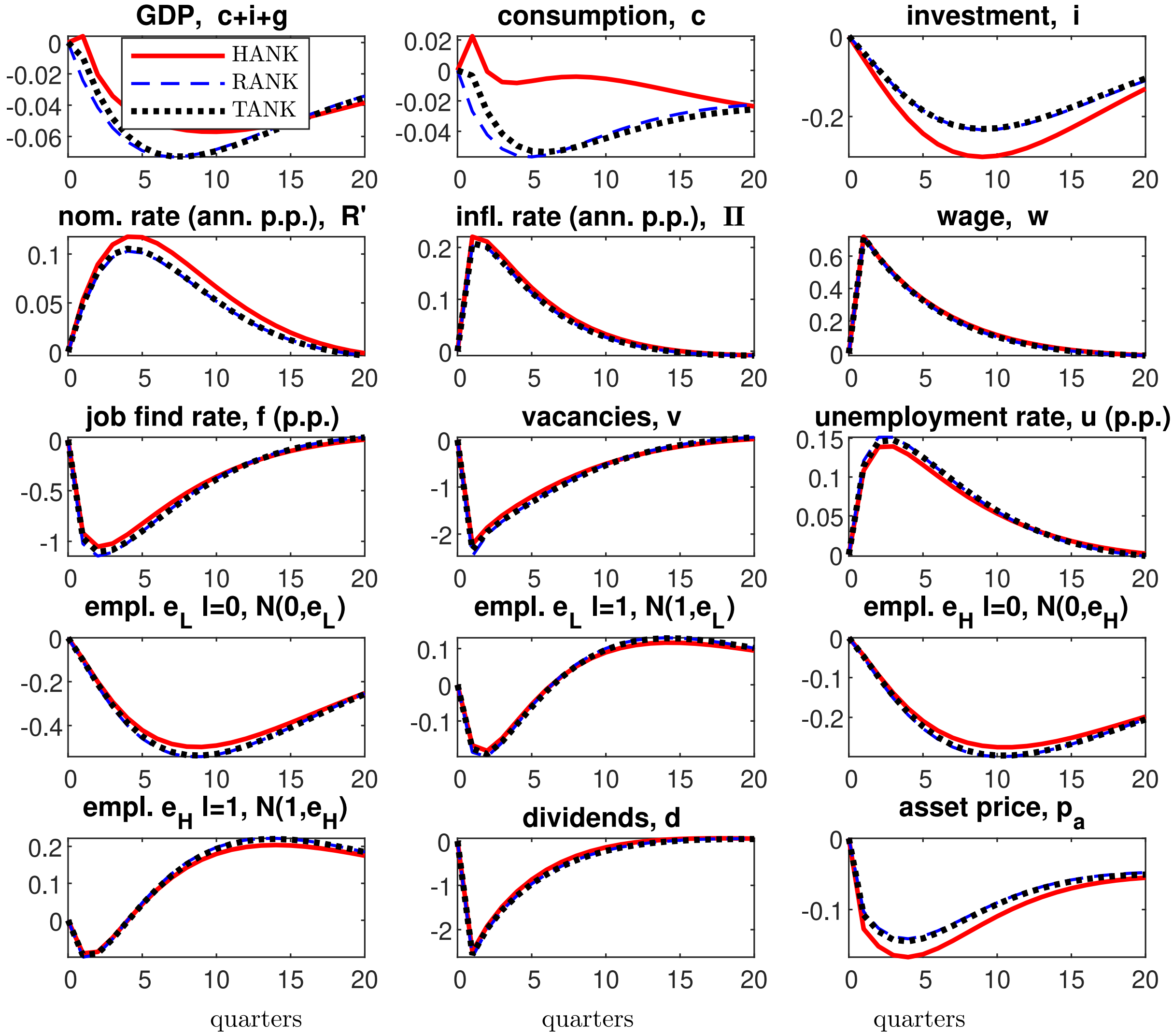
Notes: Impulse response to a one-standard-deviation price-markup shock, starting at the stochastic steady state. The shock compresses price markups. All variables expressed as percent deviations, unless noted otherwise. ann. p.p.: expressed in annualized percentage points. p.p.: expressed in percentage points.

Figure D5: Impulse response to monetary shock, ζ_R



Notes: Impulse response to a one-standard-deviation monetary shock, starting at the stochastic steady state. All variables expressed as percent deviations, unless noted otherwise. ann. p.p.: expressed in annualized percentage points. p.p.: expressed in percentage points.

Figure D6: Impulse response to wage shock, ζ_w



Notes: Impulse response to a one-standard-deviation wage-markup shock, starting at the stochastic steady state. All variables expressed as percent deviations, unless noted otherwise. ann. p.p.: expressed in annualized percentage points. p.p.: expressed in percentage points.

D.7 Variance decomposition

Table D10 reports the unconditional variance decomposition for the heterogeneous-agent economy in the main text. To compute these moments we solve for the second-order policy functions with all shocks as described in the calibration and compute the variances of the variables we are interested in, for example, consumption. We then compute the variances of each variable when we force the realizations of all but one type of shock to zero, while we keep using the policy functions we computed in the model with all the shocks. The ratio of the variance with one shock and the variance with all shocks gives us the share of the variance that each shock accounts for. As the model is non-linear given the second-order solution, these shares will not add up exactly to one as there are potential interaction effects.

Table D10: Variance decomposition HANK

variable	ζ_{TFP}	ζ_I	ζ_P	ζ_R	ζ_w
GDP, $c+i+g$	29.04	52.21	9.70	7.39	1.63
Consumption, c	23.04	60.22	5.17	7.46	1.72
Investment, i	18.06	75.24	6.24	2.15	2.59
Unemployment, U	2.96	32.90	24.44	26.15	13.94
Flow rate $U \to E$, f	3.03	33.31	23.65	26.70	13.58
Vacancies, V	2.69	29.79	17.45	24.19	10.16
Wage, W	20.31	26.14	5.96	3.18	44.34
Inflation, Π	8.48	15.38	47.69	11.15	16.90
Nominal rate, R	7.36	22.00	16.06	49.49	5.27

Notes: Forecast error variance decomposition for the heterogeneous-agent model. Contribution of respective shock (TFP, MEI, price-markup, monetary, wage) to the variance. Based on second-order dynamics with pruning. Entries in percent. Rows may not sum to 100 because of non-linear interaction effects.

E Data

This appendix summarizes the source and construction of the data that we use in the main text. Section E.1 reports on the data for wealth and income. Section E.2 reports on the data for the flow rates into and out of unemployment.

E.1 Data on wealth and income

Our data source for wealth and income is the U.S. Survey of Consumer Finances. We use the Summary Extract Public Data of the SCF 2004. Acronyms in bold below correspond to the variable names in the dataset. In the construction of different income categories we split business income between labor and financial income under the following assumptions:

- Income from non-actively managed businesses is financial income.
- Income from actively managed businesses is 60 percent labor income and 40 percent financial income, based on the average labor-income share in 2004 according to the BEA.
- As the SCF only provides the value of actively and non-actively managed businesses, but does not provide the income from both types of ventures separately, we split total business income into the two categories using the value shares as weights.

We then arrive at the following definitions of income categories:

- "Labor Income" is the sum of wage income plus the labor share of business income constructed as described above. ($WAGEINC + 0.6 \cdot \frac{ACTBUS}{BUS} \cdot BUSSEFARMINC$)
- "Social security" is social security and pension income net of withdrawals from pension accounts ($SSRETINC$ - $PENACCTWD$). We exclude pension account withdrawals, since such pensions will be treated as equity in the model. Withdrawals, therefore, will not be income. Rather, we adjust financial income each period by the putative returns to retirement accounts (see below).
- "Non-SocSec transfer income" is ($TRANSFOTHINC$). This includes among other items unemployment benefits.

- “Financial income,” then is computed as the financial part of business income $((0.4 \cdot \frac{ACTBUS}{BUS} + \frac{NONACTBUS}{BUS}) \cdot BUSSEFARMINC)$, interest and dividend income ($INTDIVINC$), realized capital gains ($KGINC$), and imputed income on other assets (labeled IMP_FININC below).

Category IMP_FININC we compute ourselves. This is necessary so as to map financial income in the model to the SCF. The SCF does not cover the rents and the service flow from owner-occupied housing. Neither does it capture financial gains on retirement accounts. Rather, both interest and dividend income and realized capital gains in the SCF are taken from IRS Form 1040. We impute the income flow from these categories. Toward this end, we first derive the average rate of return on financial assets for which we have income information, by dividing the sum of the financial part of business income, of interest and dividend income, and of realized capital gains by the stock of wealth generating them. We define this stock as the sum of the value of businesses (BUS) and total financial wealth (FIN) excluding quasi-liquid retirement accounts (RETQLIQ). The resulting real rate of return is $rret = 4.31$ percent per year (using data for all households ageds 25-99).[E10] We use this rate to impute the missing financial income by the return with the value of houses (HOUSES,ORESRE,NRESRE), other non-financial assets (OTHNFIN), and quasi-liquid retirement accounts (RETQLIQ). In addition, we also use $rret$ to impute negative income from debt secured by a primary residence (MRTHEL), debt secured by other residential property (RESDBT), credit card balances after last payment (CCBAL), other lines of credit (OTHLOC), and other debt (ODEBT). To compute total net worth we sum the value of all asset categories listed above and subtract the value of all debts listed above.

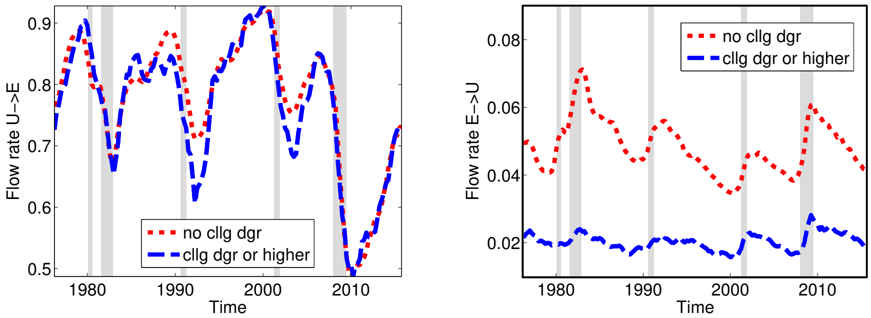
The after-tax real rate of return of 3.05 percent per year, to which we calibrate in Section 3.1, is derived as follows. Financial income as reported in the SCF is pre-tax income, where pre-tax refers to taxes paid by households. To get the households’ after-tax returns, we split the capital tax rate of 36 percent into a part paid by households and a part paid by firms, the latter of which we proxy by the average corporate tax rate over the sample period. Using the same calculations as in Fernández-Villaverde et al. (2015), the average corporate

[E10] Here we make the implicit assumption that both income and wealth are measured at the end of the period so that the ratio can be treated as the real rate of return.

tax rate over the sample is 10 percent. This leaves a 28.9 percent capital tax rate to be paid by households every quarter, implying that households' after-tax return is 3.05.[E11]

[E11] To arrive at the tax rate notice that $1 - \frac{1-0.36}{1-0.1} \approx 0.289$ taking into account that the household pays its tax on the dividends after the corporate tax have been deducted. To arrive at the post-tax return we make the following calculation: $((1.0431^{0.25} - 1) * (1 - 0.289))^4 \approx 1.0305$.

Figure E7: Data. Flow rates into (un)employment



Notes: Flow rate from unemployment to employment (left panel) and flow rate from employment to unemployment (right panel). Quarterly frequency. Based on the Current Population Survey. Workers ages 25 to 65. Red dotted line: workers without a college degree. Blue dashed: workers with a college or higher degree.

E.2 Labor-market flow rates by education

This appendix provides details on the construction of the labor-market flow rates that we rely on in calibrating the model (Section 3.2 of the main text). The flow rates are based on the Current Population Survey (CPS). We follow the methodology described in Cairó and Cajner (2018). We first compute unemployment rates and monthly flow rates from the survey. From this, we construct quarterly time series. The quarterly flow rate from unemployment to employment (the "job-finding rate") that we construct is defined as one minus the probability that a worker who was unemployed at the end of a quarter also is unemployed at the end of the next. The flow rate from employment to unemployment is constructed so as to ensure that, combined with the job-finding rate defined above, the flow rate into unemployment replicates the evolution of the unemployment rate in each education group.

The time series refer to workers ages 25–65. We split the population into two education groups. The low-education group comprises workers with less education than a completed college degree. The high-education group is composed of workers with a college degree or higher educational attainment. Figure E7 shows the resulting quarterly flow rates from unemployment to employment (left panel) and from employment to unemployment (right panel) for working-age individuals. As alluded to in the main text, the level and volatility of flow rates into employment is rather similar for the two education groups. The flow rates into unemployment, instead, differ notably by education. The flow rate into unemployment for the low-educated on average is about twice the level of the flow rate for the high-educated. It is about twice as volatile. What this means is that the low-educated are exposed to cyclical and average unemployment risk to a larger extent.

Table E11: Data. Moments of (Un)employment and Labor-Market Flow Rates

Variable	edu	std	corr	AR	mean
Unemployment rate	nclg	0.63	-0.83	0.97	5.33
	clg	0.33	-0.81	0.97	2.36
Flow rate unempl. $\rightarrow$ employ.	all	4.06	0.81	0.97	82.37
Flow rate employ. $\rightarrow$ unempl.	nclg	0.31	-0.87	0.96	4.60
	clg	0.15	-0.77	0.93	1.92

Notes: The table reports labor-market moments in the data. Second moments are based on detrended data. The trend is an HP-trend with weight 1,600 and derived on a sample from 1977Q1 to 2015Q4. The moments reported here refer to the detrended data from 1984Q1 to 2008Q3. The second column reports the sample (all workers, no college degree, or college degree first column). Thereafter, "std." reports the standard deviation of each series; "corr" shows the correlation of the series with GDP. The next column ("AR") shows the first-order autocorrelation of the series. The final column (if applicable) shows the mean of the unfiltered series.

Table E11 reports first and second moments of the resulting labor-market series. Unemployment rates are about twice as high and volatile for the low-educated as for the high-educated. For the calibration of the model, we decided to scale average unemployment rates to the average value for the whole economy; namely, so that the economy-wide unemployment rate is 6 percent (the average value for workers of all ages during our sample period). This scales the unemployment rates for each education group reported in Table E11 in proportion so that–in the model–they are 7.7 and 3.4 percent, respectively.

E.3 Time series used

This appendix describes the data that we use for estimating the shock processes (Section 3.5 in the main text) and for comparing the fit of the model to the business-cycle facts (Appendix D.5). On the one had, we rely on the data described in Appendix E.2. The unemployment and separation rates are the same as those that underly Table E11 in the Appendix. On the other hand, we resort to further time series. The data are either quarterly to start with or transformed from monthly to quarterly frequency. Unless noted otherwise, this transformation from monthly is done by averaging the monthly data over the quarter. The data are seasonally adjusted where applicable.

The source of most of the time series is the St. Louis Fed's FRED II database. Nominal variables are deflated by the GDP deflator, which we also use as our measure of inflation. Personal consumption expenditures, c, include total durable and non-durable consumption expenditures as well as services. Investment, i, is gross private domestic investment. Government consumption is government consumption and gross investment. GDP is assumed to be the sum of consumption, government expenditures, and investment. The wage, $W(X)$, is computed as wage and salary accruals from the national accounts divided by the GDP deflator divided by total nonfarm payrolls. The interest rate, R, is the quarterly average of the effective federal funds rate.

Capacity utilization, v, is measured by the quarterly average of the Board of Governors' headline index of industrial capacity utilization. We measure vacancies V using Barnichon's (2010) composite help-wanted index.

F RANK/TANK model variant

This appendix spells out the TANK model, of which the RANK model is a special case. In TANK, there are two groups of households. A mass π^{saver} of the population are savers. Savers have access to the mutual fund. Savers all have the same discount factor, β^{saver}. Savers live in a family that pools all incomes of its members. Thus, although their incomes depend on education and fluctuate with employment and retirement, their consumption is not exposed to idiosyncratic income risk or to their life-cycle income profile. The remaining households are excluded from asset markets (the spenders). Spenders have discount factor $\beta^{spend} < \beta^{saver}$. Spender households' incomes directly translate into their consumption. Incomes differ by education, skill-loss, employment status, and retirement status. For both savers and spenders, we abstract from fluctuations of skills s during working age. We also abstract from a bequest motive. The education status is assumed to be permanent. The RANK model is identical to the TANK model with savers only. In order to simplify notation, we no longer explicitly highlight the dependence on aggregate state variables. Rather, a subscript t is used to index dependence on the period t state of the economy.

F.1 Spenders

Spenders have either permanently low or permanently high education. Spenders in each education group can be in one of four idiosyncratic states: they can be unemployed, employed with an earnings loss, employed without an earnings loss, or retired. In order to preserve on notation, here we discuss incomes and the value function of low-educated spenders only. The formulae for high-education spenders are analogous. In the following, $\pi_{RET} = \pi_{s_0}$ marks the probability of retiring. π_{born} marks the probability of leaving retirement.

F.1.1 Spenders' consumption

When employed, the spender consumes $c^L_{0,t}$ if it does not suffer an earnings loss and $c^L_{1,t}$ if it does. Superscript L marks low education. Without an earnings loss, the spender consumes:

$$c^{L,spend}_{0,t}(1+\tau_c) = w_t e_L[1 - \tau_{RET} - \tau_{UI} - \tau_t(w_t e_L)],$$

where $\tau_t(\cdot)$ is the progressive income tax function. With an earnings loss, the spender consumes:

$$c_{1,t}^{L,spend}(1+\tau_c) = w_t e_L(1-\varrho)[1-\tau_{RET}-\tau_{UI}-\tau_t(w_t e_L(1-\varrho))].$$

When unemployed, the spender consumes $c_{U,t}^{L}$, where the U marks the unemployment state:

$$c_{U,t}^{L,spend}(1+\tau_c) = b_{UI}(e_L)[1-\tau_t(b_{UI}(e_L))].$$

Last, when retired, the spender household consumes

$$c_{R,t}^{L,spend}(1+\tau_c) = b_{RET}(e_L)[1-\tau(b_{RET}(e_L))].$$

F.1.2 Value function of spenders

With this, and the labor-market transitions, the value of the spender household is as follows. If employed, without an earnings loss

$$\begin{aligned} W_{0,t}^{L,spend} \quad = \quad & (1-\beta^{spend})\tfrac{(c_{0,t}^{L,spend})^{1-\sigma}}{1-\sigma} \\ & +\beta^{spend}\pi_{RET}\mathbb{E}_t\{W_{R,t+1}^{L,spend}\} \\ & +\beta^{spend}(1-\pi_{RET})\mathbb{E}_t\{(1-\lambda_x^L-\lambda_e^L(1-f_{t+1}))W_{0,t+1}^{L,spend}\} \\ & +\beta^{spend}(1-\pi_{RET})\mathbb{E}_t\{(\lambda_x^L+\lambda_e^L(1-f_{t+1}))W_{U,t+1}^{L,spend}\}. \end{aligned}$$

If employed, with an earnings loss

$$\begin{aligned} W_{1,t}^{L,spend} \quad = \quad & (1-\beta^{spend})\tfrac{(c_{1,t}^{L,spend})^{1-\sigma}}{1-\sigma} \\ & +\beta^{spend}\pi_{RET}\mathbb{E}_t\{W_{R,t+1}^{L,spend}\} \\ & +\beta^{spend}(1-\pi_{RET})\pi_L^{emp}(1,0)\mathbb{E}_t\{(1-\lambda_x^L-\lambda_e^L(1-f_{t+1}))W_{0,t+1}^{L,spend}\} \\ & +\beta^{spend}(1-\pi_{RET})\pi_L^{emp}(1,1)\mathbb{E}_t\{(1-\lambda_x^L-\lambda_e^L(1-f_{t+1}))W_{1,t+1}^{L,spend}\} \\ & +\beta^{spend}(1-\pi_{RET})\mathbb{E}_t\{(\lambda_x^L+\lambda_e^L(1-f_{t+1}))W_{U,t+1}^{L,spend}\}. \end{aligned}$$

If unemployed

$$
\begin{aligned}
W_{U,t}^{L,spend} \quad = \quad & (1-\beta^{spend})\frac{(c_{U,t}^{L,spend})^{1-\sigma}}{1-\sigma} \\
& +\beta^{spend}\pi_{RET}\mathbb{E}_t\{W_{R,t+1}^{L,spend}\} \\
& +\beta^{spend}(1-\pi_{RET})\mathbb{E}_t\{f_{t+1}\pi_L^{uem}(0)W_{0,t+1}^{L,spend}\} \\
& +\beta^{spend}(1-\pi_{RET})\mathbb{E}_t\{f_{t+1}\pi_L^{uem}(1)W_{1,t+1}^{L,spend}\} \\
& +\beta^{spend}(1-\pi_{RET})\mathbb{E}_t\{(1-f_{t+1})W_{U,t+1}^{L,spend}\}.
\end{aligned}
$$

If retired

$$
\begin{aligned}
W_{R,t}^{L,spend} \quad = \quad & (1-\beta^{spend})\frac{(c_{R,t}^{L,spend})^{1-\sigma}}{1-\sigma} \\
& +\beta^{spend}(1-\pi_{born})\mathbb{E}_t\{W_{R,t+1}^{L,spend}\} \\
& +\beta^{spend}\pi_{born}\mathbb{E}_t\{(\mathrm{Pr}_{0,t}^L(1-\lambda_x^L-\lambda_e^L(1-f_{t+1}))+\mathrm{Pr}_{U,t}^L f_{t+1}\pi_L^{uem}(0))W_{0,t+1}^{L,spend}\} \\
& +\beta^{spend}\pi_{born}\mathbb{E}_t\{(\mathrm{Pr}_{1,t}^L(1-\lambda_x^L-\lambda_e^L(1-f_{t+1}))+\mathrm{Pr}_{U,t}^L f_{t+1}\pi_L^{uem}(1))W_{1,t+1}^{L,spend}\} \\
& +\beta^{spend}\pi_{born}\mathbb{E}_t\{[(\mathrm{Pr}_{0,t}^L+\mathrm{Pr}_{1,t}^b)(\lambda_x^L+\lambda_e^L(1-f_{t+1}))+\mathrm{Pr}_{U,t}^L(1-f_{t+1})]W_{U,t+1}^{L,spend}\}.
\end{aligned}
$$

Where the probabilities Pr^L of being reborn into the respective group are defined as

$$
\mathrm{Pr}_{0,t}^L = (N_{0,t}^L + N_{1,t}^L\pi^{emp}(1,0))/(N_t^L+U_t^L),
$$

$$
\mathrm{Pr}_{1,t}^L = (N_{1,t}^L\pi^{emp}(1,1))/(N_t^L+U_t^L),
$$

$$
\mathrm{Pr}_{U,t}^L = U_t^L/(N_t^L+U_t^L).
$$

The same relations above hold for the highly educated, replacing index L with H.

F.2 Savers

Savers are exposed to the same income risk as spenders. They are not exposed to idiosyncratic consumption risk, however. Rather, savers live in a representative family that encompasses all the different household types (low/high education; employed with/without earnings loss; unemployed; retired). The family pools the incomes of its members.

Saver families maximize expected lifetime utility

$$\max_{\{c_t, a_{t+1}\}_{t=0}^{\infty}} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t (c_t^{saver})^{1-\sigma}/(1-\sigma) \right\}$$

subject to the family's budget constraint

$$\begin{aligned}
(1+\tau_c)c_t^{saver} + p_{a,t}a_{t+1} \quad = \quad & (p_{a,t} + d_{a,t})a_t \\
& + \pi^{\text{saver}} U_t^L b_{UI}(e_L)[1 - \tau_t(b_{UI}(e_L))] \\
& + \pi^{\text{saver}} U_t^H b_{UI}(e_H)[1 - \tau_t(b_{UI}(e_H))] \\
& + \pi^{\text{saver}} N_{0,t}^L w_t e_L [1 - \tau_{RET} - \tau_{UI} - \tau_t(w_t e_L)] \\
& + \pi^{\text{saver}} N_{0,t}^H w_t e_H [1 - \tau_{RET} - \tau_{UI} - \tau_t(w_t e_H)] \\
& + \pi^{\text{saver}} N_{1,t}^L w_t e_L (1-\varrho)[1 - \tau_{RET} - \tau_{UI} - \tau_t(w_t e_L(1-\varrho))] \\
& + \pi^{\text{saver}} N_{1,t}^H w_t e_H (1-\varrho)[1 - \tau_{RET} - \tau_{UI} - \tau_t(w_t e_H(1-\varrho))] \\
& + \pi^{\text{saver}} (1 - \pi^{\text{labforce}}) \pi_E(e_L) b_{RET}(e_L)[1 - \tau_t(b_{RET}(e_L))] \\
& + \pi^{\text{saver}} (1 - \pi^{\text{labforce}}) \pi_E(e_H) b_{RET}(e_H)[1 - \tau_t(b_{RET}(e_H))],
\end{aligned}$$

where $\pi^{\text{labforce}} (= \pi_S(\mathcal{S}_+))$ is the share of households in the labor force. The exposition above assumes that savers trade shares in the mutual fund. We make this assumption so as to keep the exposition close to the heterogeneous-household's baseline. We could as well have had each saver family decide directly over a portfolio of non-financial firms.

F.3 Financial firms

The firm side of the TANK variant is identical to the heterogeneous-agent version, with the exception that only saver families own shares in the representative mutual fund. The mutual funds trade the equity of all firms. Being owned by savers only, the mutual funds' discount factor is $Q_{t,t+1} = \beta^{saver}(c_{t+1}^{saver}/c_t^{saver})^{-\sigma}$. The central bank steers the inter-fund interest rate, R_t, resulting in the consumption Euler equation $1 = \mathbb{E}_t\{Q_{t,t+1}R_t/\Pi_{t+1}\}$. The mutual fund distributes to shareholders all income that it does not reinvest or use for paying adjustment costs. After-tax dividends are given by

$$d_{a,t} = (1-\tau_d)\Big(y_t - \frac{\psi}{2}\left(\Pi_t - \bar{\Pi}\right)^2 y_t + \kappa_t M_t - \Xi - i_t$$
$$-N^L_{0,t} w_t e_L - N^H_{0,t} w_t e_H - N^L_{1,t} w_t e_L (1-\varrho) - N^H_{1,t} w_t e_H (1-\varrho)\Big)$$

F.4 Non-financial firms

Non-financial firms are identical to the firms in the heterogeneous-agent model.

F.4.1 Final goods

There is a representative competitive final-goods firm that transforms differentiated intermediate goods into homogeneous final goods. Final goods can be used for personal consumption expenditures, government consumption, and physical investment. The firm solves

$$\max_{y_t,(y_{j,t})_{j\in[0,1]}} (1-\tau_d)\left(P_t y_t - \int_0^1 P_{j,t} y_{j,t} dj\right) \text{ s.t. } y_t = \left(\int_0^1 y_{j,t}^{\frac{\vartheta \exp\{\zeta_{P,t}\}-1}{\vartheta \exp\{\zeta_{P,t}\}}} dj\right)^{\frac{\vartheta \exp\{\zeta_{P,t}\}}{\vartheta \exp\{\zeta_{P,t}\}-1}},$$

where $\vartheta > 1$. y_t marks the output of final goods. $P_{j,t}$ marks the price of differentiated input j and $y_{j,t}$ denotes the quantity demanded of that input by final-goods firms. P_t is the consumer price index.

F.4.2 Intermediate inputs

Next to final goods, there are intermediate inputs, as in the heterogeneous-household model.

Differentiated goods producers. There is a unit mass of producers of differentiated goods. Producer $j \in [0,1]$ solves

$$\max_{\{P_{j,t},\ell_{j,t},k_{j,t}\}_{t=0}^{\infty}} \mathbb{E}_0 \Big\{ \sum_{t=0}^{\infty} Q_{0,t}(1-\tau_d) \Big(y_{j,t}\left(\frac{P_{j,t}}{P_t}\right) - \Xi - r_t k_{j,t} - h_t \ell_{j,t}$$
$$-\frac{\psi}{2}\left(\frac{P_{j,t}}{P_{j,t-1}} - \overline{\Pi}\right)^2 y_t \Big)\Big\}$$

$$s.t. \quad y_{j,t} = \zeta_{TFP,t} k_{j,t}^{\theta} \ell_{j,t}^{1-\theta},$$
$$y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\vartheta \exp\{\zeta_{P,t}\}} y_t,$$
$$P_{j,-1} \text{ given.}$$

Labor services. Labor services are homogeneous. They are produced by employment agencies, under constant returns to scale. Workers come in four types to the agency: low/high education each with/without skill loss. The value to the agency of a household to the employment agency depends on the household's characteristics. The value the agency of a low-educated worker without skill loss is

$$J^L_{L,0,t} = (1-\tau_d)(h_t - w_t)e_L + \mathbb{E}_t\big\{Q_{t,t+1}\big(1-\lambda_x(e_L)+\lambda_n(e_L)\big)J^L_{L,0,t+1}\big\}.$$

The value to the agency of a low-educated worker with skill loss is

$$\begin{aligned} J^L_{L,1,t} &= (1-\tau_d)(h_t - w_t)e_L(1-\varrho) \\ &\quad + \mathbb{E}_t\big\{Q_{t,t+1}\big(1-\lambda_x(e_L)+\lambda_n(e_L)\big)\big(\pi^{emp}_L(1,0)J^L_{L,0,t+1} + \pi^{emp}_L(1,1)J^L_{L,1,t+1}\big)\big\}. \end{aligned}$$

The value to the agency of a high-educated worker without skill loss is

$$J^H_{L,0,t} = (1-\tau_d)(h_t - w_t)e_H + \mathbb{E}_t\big\{Q_{t,t+1}\big(1-\lambda_x(e_H)+\lambda_n(e_H)\big)J^H_{L,0,t+1}\big\}.$$

The value to the agency of a high-educated worker with skill loss is

$$\begin{aligned} J^H_{L,1,t} &= (1-\tau_d)(h_t - w_t)e_H(1-\varrho) \\ &\quad + \mathbb{E}_t\big\{Q_{t,t+1}\big(1-\lambda_x(e_H)+\lambda_n(e_H)\big)\big(\pi^{emp}_H(1,0)J^H_{L,0,t+1} + \pi^{emp}_L(1,1)J^H_{L,1,t+1}\big)\big\}. \end{aligned}$$

After separations have occurred, and before production, employment agencies can recruit new households. Let V_t be the aggregate number of vacancies posted and M_t the mass of new matches. The job-filling probability is identical for all vacancies, and given by $q_t = M_t/V_t$. Letting κ_t/q_t be the average cost per hire, the free-entry condition for recruiting is given by

$$\begin{aligned} &[\widetilde{U}^L_t \pi^{uem}_L(0) + \lambda_n(e_L)\widetilde{N}^L_{0,t}]J^L_{L,0,t} \\ &+[\widetilde{U}^L_t \pi^{uem}_L(1) + \lambda_n(e_L)\widetilde{N}^L_{1,t}]J^L_{L,1,t} \\ &+[\widetilde{U}^H_t \pi^{uem}_L(0) + \lambda_n(e_H)\widetilde{N}^H_{0,t}]J^H_{L,0,t} \\ &+[\widetilde{U}^H_t \pi^{uem}_L(1) + \lambda_n(e_H)\widetilde{N}^H_{1,t}]J^H_{L,1,t} = (1-\tau_d)\kappa_t \cdot \Big[\widetilde{U}^L_t + \lambda_n(e_L)\widetilde{N}^L_t + \widetilde{U}^H_t + \lambda_n(e_L)\widetilde{N}^H_t\Big]. \end{aligned}$$

Recruiting costs are given by

$$\kappa_t = \kappa \left(\frac{M_t/\widetilde{N}_t}{\overline{M}/\overline{\widetilde{N}}} \right)^2 .$$

Matches emerge according to matching function

$$M_t = \left[\left(\widetilde{U}_t + \lambda_n(e_L)\widetilde{N}_t^L + \lambda_n(e_H)\widetilde{N}_t^H \right) V_t \right] / \left(\left(\widetilde{U}_t + \lambda_n(e_L)\widetilde{N}_t^L + \lambda_n(e_H)\widetilde{N}_t^H \right)^\alpha + V_t{}^\alpha \right)^{\frac{1}{\alpha}}$$

with $\alpha > 0$. The job-finding rate is

$$f_t = \frac{M_t}{\widetilde{U}_t + \lambda_n(e_L)\widetilde{N}_t^L + \lambda_n(e_H)\widetilde{N}_t^H}.$$

The wage rule is

$$\log(w_t/\overline{w}) = \phi_w \, \log(w_{t-1}/\overline{w}) + \phi_w \, \log\left(\frac{y_t}{\overline{y}}\right) + \zeta_{w,t}.$$

Capital services. The representative producer of capital services faces the following problem

$$\begin{array}{ll} \max_{\{v_t, i_t, K_t\}_{t=0}^{\infty}} & \mathbb{E}_0 \Big\{ \sum_{t=0}^{\infty} (1-\tau_d)(r_t K_{t-1} v_t - i_t) \Big\} \\ & \text{s.t.} \qquad K_t = \big[1 - \delta(v_t)\big] \cdot K_{t-1} + \zeta_{I,t} \cdot [1 - \Gamma(i_t/i_{t-1})] i_t. \end{array}$$

Depreciation of capital evolves as

$$\delta(v_t) = \delta_0 + \delta_1 \, (v_t^{\delta_2} - 1), \;\; \delta_0, \delta_1 > 0, \delta_2 > 1.$$

The transformation function that governs how investment is transformed into physical capital is given by

$$\Gamma\left(\frac{i_t}{i_{t-1}}\right) = \phi_K/2 \left(\frac{i_t}{i_{t-1}} - 1\right)^2, \;\; \phi_K \geq 0.$$

F.5 Central bank and fiscal authority

The central bank sets the gross nominal interest rate according to Taylor rule

$$\begin{aligned} \log\left(\tfrac{R_t}{\overline{R}}\right) \;\; = \;\; & \phi_R \log\left(\tfrac{R_{t-1}}{\overline{R}}\right) \\ & + (1-\phi_R)\left[\phi_\Pi \log\left(\tfrac{\Pi_t}{\overline{\Pi}}\right) - \phi_u \left(\tfrac{U_t - \overline{U}}{\pi^{\text{labforce}}}\right)\right] + \log \zeta_{R,t}. \end{aligned}$$

The fiscal authority's budget constraint is given by

$$
\begin{aligned}
& g \\
& +U_t^L b_{UI}(e_L)[1-\tau_t(b_{UI}(e_L))] \\
& +U_t^H b_{UI}(e_H)[1-\tau_t(b_{UI}(e_H))] \\
& +(1-\pi^{\text{labforce}})\pi_E(e_L) b_{RET}(e_L)[1-\tau_t(b_{RET}(e_L))] \\
& +(1-\pi^{\text{labforce}})\pi_E(e_H) b_{RET}(e_H)[1-\tau_t(b_{RET}(e_H))] \\
= \quad & \tau_c c_t \\
& +\tau_d \bigg(y_t - \Xi - (\tfrac{\psi}{2}(\Pi_t - \overline{\Pi})^2 y_t) - \kappa_t M_t - i_t - \\
& \qquad w_t e_L[N_{0,t}^L + N_{1,t}^L(1-\varrho)] - w_t e_H[N_{0,t}^H + N_{1,t}^H(1-\varrho)] \bigg) \\
& +N_{0,t}^L w_t e_L[\tau_{RET} + \tau_{UI} + \tau_t(w_t e_L)] \\
& +N_{1,t}^L w_t e_L(1-\varrho)[\tau_{RET} + \tau_{UI} + \tau_t(w_t e_L(1-\varrho))] \\
& +N_{0,t}^H w_t e_H[\tau_{RET} + \tau_{UI} + \tau_t(w_t e_H)] \\
& +N_{1,t}^H w_t e_H(1-\varrho)[\tau_{RET} + \tau_{UI} + \tau_t(w_t e_H(1-\varrho))]
\end{aligned} \tag{6}
$$

F.6 Laws of motion (un)employment

We list both (un)employment at the beginning of the period and at the end of the period.

F.6.1 (Un)employment at the beginning of the period

Low-education, no skill loss employment at the beginning of the period evolves as

$$\widetilde{N}_{0,t}^L = N_{0,t-1}^L + \pi^{emp}(1,0) N_{1,t-1}^L.$$

With skill loss, the corresponding law of motion is

$$\widetilde{N}_{1,t}^L = \pi^{emp}(1,1) N_{1,t-1}^L.$$

Total low-education employment at the beginning of the period is

$$\widetilde{N}_t^L = \widetilde{N}_{0,t}^L + \widetilde{N}_{1,t}^L.$$

High-education, no skill loss employment at the beginning of the period evolves as

$$\widetilde{N}_{0,t}^H = N_{0,t-1}^H + \pi^{emp}(1,0)N_{1,t-1}^H.$$

With skill loss, the corresponding law of motion is

$$\widetilde{N}_{1,t}^H = \pi^{emp}(1,1)N_{1,t-1}^H.$$

Total high-education employment at the beginning of the period is

$$\widetilde{N}_t^H = \widetilde{N}_{0,t}^H + \widetilde{N}_{1,t}^H.$$

Total employment at the beginning of the period evolves as

$$\widetilde{N}_t = \widetilde{N}_t^L + \widetilde{N}_t^H.$$

Unemployment at the beginning of the period is defined as

$$\widetilde{U}_t^L = \pi_E(e_L)\pi^{\text{labforce}} - \widetilde{N}_t^L,$$

$$\widetilde{U}_t^H = \pi_E(e_H)\pi^{\text{labforce}} - \widetilde{N}_t^H,$$

and

$$\widetilde{U}_t = \widetilde{U}_t^L + \widetilde{U}_t^H.$$

F.6.2 (Un)employment at the end of the period

Low-education employment at the end of the period evolves as

$$N_{0,t}^L = [1 - \lambda_x(e_L) - \lambda_e(e_L)(1 - ft)]\widetilde{N}_{0,t}^L + f_t\pi_L^{uem}(0)U_{t-1}^L.$$

$$N_{1,t}^L = [1 - \lambda_x(e_L) - \lambda_e(e_L)(1 - ft)]\widetilde{N}_{1,t}^L + f_t\pi_L^{uem}(1)U_{t-1}^L.$$

$$N_t^L = N_{0,t}^L + N_{1,t}^L.$$

High-education employment at the end of the period evolves as

$$N_{0,t}^{H} = [1 - \lambda_x(e_H) - \lambda_e(e_H)(1 - ft)]\widetilde{N}_{0,t}^{H} + f_t \pi_H^{uem}(0) U_{t-1}^{H}.$$

$$N_{1,t}^{H} = [1 - \lambda_x(e_H) - \lambda_e(e_H)(1 - ft)]\widetilde{N}_{1,t}^{H} + f_t \pi_H^{uem}(1) U_{t-1}^{H}.$$

$$N_t^H = N_{0,t}^H + N_{1,t}^H.$$

Employment at the end of the period evolves as

$$N_t = N_{0,t}^L + N_{1,t}^L + N_{0,t}^H + N_{0,t}^H.$$

Unemployment at the end of the period evolves as

$$U_t^L = \pi_E(e_L)\pi^{\text{labforce}} - N_t^L,$$

$$U_t^H = \pi_E(e_H)\pi^{\text{labforce}} - N_t^H,$$

and

$$U_t = U_t^L + U_t^H.$$

F.7 Aggregates

Total per-capita consumption of spenders is

$$\begin{aligned} c_t^{\text{spend}} \quad = \quad & (1 - \pi^{\text{labforce}})\pi_E(e_L)c_{R,t}^{L,spend} + (1 - \pi^{\text{labforce}})\pi_E(e_H)c_{R,t}^{H,spend} \\ & + U_t^L c_{U,t}^{L,spend} + U_t^H c_{U,t}^{H,spend} \\ & + N_{0,t}^L c_{0,t}^{L,spend} + N_{1,t}^L c_{1,t}^{L,spend} \\ & + N_{0,t}^H c_{0,t}^{H,spend} + N_{1,t}^H c_{1,t}^{H,spend}. \end{aligned}$$

Total consumption is

$$c_t = \pi^{\text{saver}} c_t^{\text{saver}} + (1 - \pi^{\text{saver}}) c_t^{\text{spend}}.$$

F.8 Market clearing and equilibrium

The market for capital services clears if (with $k_{j,t} = k_t$ for all j)

$$v(X)K_{t-1} = k_t.$$

The market for labor services clears if all labor services supplied are used in the production of differentiated goods (with $\ell_{j,t} = \ell_t$ for all j),

$$N^L_{0,t}e_L + N^L_{1,t}e_L(1-\varrho) + N^H_{0,t}e_H + N^H_{1,t}e_H(1-\varrho) = \ell_t.$$

The market for differentiated goods clears if demand equals production (using symmetry in both price setting and demand for each differentiated good j), so

$$y_t = \zeta_{TFP,t}k_t^{\theta}\ell_t^{1-\theta}.$$

The market for final goods clears if

$$y_t = c_t + i_t + g + \frac{\psi}{2}\left(\Pi_t - \overline{\Pi}\right)^2 y_t + \kappa_t M_t.$$

Normalizing the supply of shares to unity, the market for shares in the mutual fund clears if

$$a_t = 1.$$

F.9 Marginal propensities to consume

This appendix documents household's marginal propensity to consume (MPC). To document the MPCs for our model, we perform the following experiment. We are interested in the individual household's consumption response to an exogenous one-time increase in income. A household is characterized by its state (n, a, l, e, b, s). At the beginning of the quarter, we give the model-equivalent of \$500 in wealth to a household (and to that household only). Then, we record the cumulative increase in consumption expenditure as a share of the initial gift over the next quarter, the next two quarters, three quarters, and four quarters. We focus on the economy's non-stochastic steady state. That is, for the experiment shown here, all aggregate shocks ζ are known to be zero in all time periods. Endogenous aggregate variables have settled to their long-run value. While the aggregate state of the economy remains fixed in this experiment, the household still faces idiosyncratic risk (for example, idiosyncratic income and employment risk), thus, we allow the household's individual states to change over time. Table F12 summarizes group averages for MPS. It shows the average MPCs for different groups of households (first four columns, in percent of the initial increase in income), where households are grouped by their characteristics at the time of the transfer. The last column reports the share of these households in the population.

The first line shows the average MPC for the entire economy, giving equal weight to all households. In the first quarter, the average MPC is 15.4 percent. After a year, on average households have spent – for consumption – a third of the increase in income (an MPC of 33.4 percent). This is in line with the evidence summarized in Carroll et al. (2017), for example. They conclude that most empirical estimates in the literature find aggregate annual MPCs of 20 to 60 percent over a yearly horizon.[F12]

The average MPC may be an incomplete guide, however. The reason is that a change systematic stabilization policy and different shocks impact different sources of income differentially, so that households in different idiosyncratic states might respond differently to a given shock. For example, a rise in wages does not benefit the retired or unemployed directly, while it raises the labor earnings of the employed. Therefore, the table also shows

[F12] The heterogeneity in discount factors is an important factor for the average MPC, as discussed in Carroll et al. (2017).

Table F12: Cumulative Marginal Propensity to Consume (in percent)

	Cumul. MPC after quarter				Fraction of households
	1	2	3	4	
All	15.4	24.1	29.3	33.4	100
By wealth					
$\leq$ Wealth25	46.5	67.4	75.9	80.6	25.0
Wealth25-Wealth50	9.6	18.0	25.4	31.9	25.0
Wealth50-Wealth75	3.3	6.5	9.6	12.6	25.0
Wealth75+	2.2	4.3	6.5	8.5	25.0
By age and employment					
working age, $n = 1$, $l = 0$	13.7	22.7	28.6	33.1	25.5
working age, $n = 1$, $l = 1$	21.3	32.3	38.2	42.6	46.8
working age, unempl., $n = 0$	25.8	36.4	42.0	46.0	4.6
retired (s_0)	3.2	6.4	9.6	12.7	23.1
Working age, by skill					
s_1 (low)	28.4	41.3	46.8	50.3	38.1
s_2 (medium)	10.0	17.8	24.1	29.4	38.1
s_3 (high)	4.2	8.1	11.7	15.1	0.8
By education and patience					
β_{e_L}, low edu., patient	4.2	8.0	11.5	14.6	30.0
β_{e_H}, high edu., patient	1.9	3.8	5.7	7.6	20.0
$\beta_{e_L} - \Delta\beta$, low edu., impatient	28.9	44.4	53.0	59.0	30.0
$\beta_{e_H} - \Delta\beta$, high edu., impatient	25.2	37.7	44.2	49.1	20.0

Notes: The table shows the share of a \$500 gift to an individual household that is spent after one quarter, two quarters, three quarters, and four quarters in the deterministic steady state. Column 'Fraction of households' denotes the percentage of the population in the respective group at the beginning of the first quarter. As per the rows, 'All' contains all households and reports the aggregate average MPC. Rows 'By wealth' split households into four equally sized groups by wealth and reports their respective MPCs with '$\leq$Wealth25' being the lowest wealth quartile and 'Wealth75+' being the highest. 'By age and employment' reports average MPCs for the retired (s_0), and three groups of working-age households. The first are the employed without skill loss ($n = 1, l = 0, s \in \mathcal{S}_+$), the next the employed with skill loss ($n = 1, l = 1, s \in \mathcal{S}_+$). Last, there are the unemployed households ($n = 0, s \in \mathcal{S}_+$). 'retired' contains all the retired households ($s = s_0$). 'Working age, by skill' groups the working-age households by their skill level (from s_1 (lowest) to s_3 (highest)). 'By education and patience' reports results for the different time preferences. 'β_{e_L}' summarizes the low-educated households with high β. 'β_{e_H}' describes the high-educated households with high β. The next two rows contain the same education groups but with lower β (impatient). For each of the groups, membership is determined at the beginning of the first quarter, before the gift is given. Households are allowed to transit to different states thereafter. Shares do not necessarily add up to 100 due to rounding.

the MPCs for different subgroups of the population. As before, households are assigned to groups on the basis of their characteristics at the time of the gift and we allow households to transit to other states thereafter. The first set of subgroups splits the population by wealth quartile. Next, we separate households by employment and age. The third block shows the MPCs for different levels of idiosyncratic productivity, while the final block looks at MPCs for households with different time preferences.

The results in the table can be summarized as follows. As is typical in models like ours the MPC decreases in wealth. The wealth-poorest 25 percent of households ("$\leq$ Wealth25") spend about 81 percent of the gift within a year. The wealth-richest 25 percent ("Wealth75+"), instead, convert only roughly 9 percent of the gift into consumption within a year. Looking over the employment states we see that employed households without skill loss ("working age, $n = 1$, $l = 0$") spend about 1/3 of the gift within a year as they tend to be wealth-richer and tend to save both to insure against unemployment risk and for retirement. Employed households with a skill loss ("working age, $n = 1$, $l = 1$") and unemployed households ("working age, $n = 0$") have a significantly higher MPC. These households are wealth-poorer on average, as they have earlier used some of their wealth to stabilize consumption. In addition, they hope for a likely rise in income in case their employment or skill-loss state improves. Finally, retired households supplement their low but secure social security income by financial income. These households, thus, tend to be relatively wealthy. This and the desire to leave bequests mean that the old have lower MPCs than the working-age households. The same analysis can be applied to the effects of household skills. Finally, the MPC is decreasing in a household's patience. This is so because of both the direct effect of more forward-looking behavior and the induced stock of savings. Our calibration to the wealth distribution implies that lower-educated households tend to be less patient, and so tend to have higher MPCs.

G Adjusting for the effect on average inflation

This section reports how we implement the adjustment to the Taylor rule for any parameterization to keep average inflation at the central bank's inflation target. This is done as follows. We adjust Taylor rule (4) by a term that shifts the nominal rate in the stochastic economy (but leaving the non-stochastic steady state in place). Let $\epsilon_t^{\text{adjust}}$ be a white noise standard normal shock. The adjusted Taylor rule takes the form:

$$\begin{aligned}\log\left(\tfrac{R(X)}{\overline{R}}\right) \quad = \quad & \phi_R \log\left(\tfrac{R_{-1}(X)}{\overline{R}}\right) \\ & +(1-\phi_R)\left[\phi_\Pi \log\left(\tfrac{\Pi(X)}{\overline{\Pi}}\right) + \phi_\epsilon E_t\left\{\left(\epsilon_{t+1}^{\text{adjust}}\right)^2\right\} - \phi_u\left(\tfrac{U(X)-\overline{U}}{\pi_S(\mathcal{S}_+)}\right)\right].\end{aligned} \tag{7}$$

Note that the term involving the expectation is a constant that appears only in the stochastic version of the model, but not in the non-stochastic steady state. It also does not affect the model in any other way beside shifting the level of the rule. For each parameterization of the rule, we choose a ϕ_ϵ such that the average inflation rate stays at the target level of 2 percent annualized throughout. In order to implement this practically, we make use of the Andreasen et al. (2018) moment formulas to compute average inflation precisely. In addition, it is easy to see that the second-order model solution is affine-linear in ϕ_ϵ so that we effectively only have to solve the model for two values of ϕ_ϵ and then search for the linear combination of the two that holds average inflation at 2 percent.

H Transitional dynamics

This appendix details the computation of average transitional dynamics. We build on Andreasen et al. (2018), the notation of which we use below. The first-order dynamics of the state equations are given by

$$x_{t+1}^f = h_x x_t^f + \eta \epsilon_{t+1}$$

The state equation's second-order dynamics are:

$$x_{t+1}^s = h_x x_t^s + \frac{1}{2} H_{xx}\left(x_t^f \otimes x_t^f\right) + \frac{1}{2} h_{\sigma\sigma}$$

The jump variables' policy function is:

$$y_t^s = g_x(x_t^f + x_t^s) + \frac{1}{2}G_{xx}\left(x_t^f \otimes x_t^f\right) + \frac{1}{2}g_{\sigma\sigma}.$$

We want to find the mean change from a point $(\bar{x}^f, \bar{x}^s)$. It is easy to see that if we can find the component terms for the means of x, we get the mean of y "for free." That is, we can focus on x. The mean dynamics for $E_0\left(x_h^f\right)$ are given by

$$E_0\left(x_h^f\right) = h_x^h \bar{x}^f$$

The dynamics for $\mathbb{E}_0(x_h^f \otimes x_h^f)$ are given by

$$\begin{aligned}
\mathbb{E}_0(x_h^f \otimes x_h^f) &= \mathbb{E}_0\left(\left(h_x^h\bar{x}^f + \sum_{j=1}^{h} h_x^{h-j}\eta\epsilon_j\right) \otimes \left(h_x^h\bar{x}^f + \sum_{j=1}^{h} h_x^{h-j}\eta\epsilon_j\right)\right) \\
&= \left(h_x^h\bar{x}^f\right) \otimes \left(h_x^h\bar{x}^f\right) + \mathbb{E}_0\left(\sum_{j=1}^{h} h_x^{h-j}\eta\epsilon_j \otimes \sum_{j=1}^{h} h_x^{h-j}\eta\epsilon_j\right) \text{ (as corr}(\epsilon_h, \bar{x}^f)\text{=0)} \\
&= \left(h_x^h\bar{x}^f\right) \otimes \left(h_x^h\bar{x}^f\right) + \sum_{j=1}^{h} \mathbb{E}_0\left(h_x^{h-j}\eta\epsilon_j \otimes h_x^{h-j}\eta\epsilon_j\right) \text{ (as corr}(\epsilon_h, \epsilon_k)\text{=0)},\ h \neq k \\
&= \left(h_x^h\bar{x}^f\right) \otimes \left(h_x^h\bar{x}^f\right) + \sum_{j=1}^{h} \mathbb{E}_0\left(h_x^{h-j}\eta \otimes h_x^{h-j}\eta\right)(\epsilon_j \otimes \epsilon_j) \\
&= \left(h_x^h\bar{x}^f\right) \otimes \left(h_x^h\bar{x}^f\right) + \sum_{j=1}^{h} \mathbb{E}_0\left(h_x^{h-j}\eta \otimes h_x^{h-j}\eta\right) vec(I_{nshocks}).
\end{aligned}$$

Dynamics for $\mathbb{E}_0(x_h^s)$:

$$\mathbb{E}_0(x_h^s) = h_x^h\bar{x}^s + 0.5\sum_{j=1}^{h} h_x^{h-j}\left(H_{xx}\mathbb{E}_0(x_{j-1}^f \otimes x_{j-1}^f) + h_{\sigma\sigma}\right)$$

I Markup channel

The discussion in Section 4.3 of the main text highlighted that a stronger focus on stabilizing inflation induces price setters to choose higher average markups. The Section also emphasized that this rise in markups means that the supply of financial assets rises, and that this induces a pronounced change in the capital stock in the HANK economy but not in RANK/TANK.

The current appendix, first, shows by pencil and paper how the average-markup effect arises from the New Keynesian Phillips curve in the presence of price markup shocks (Appendix I.1). Second, it shows the elasticity of capital and the real rate in the steady-state of the HANK model to a rise in pure profits, and compares this RANK/TANK (Appendix I.2).

I.1 Deriving the markup channel from the Phillips curve

Consider the non-linear New Keynesian Phillips curve, equation (5) in Appendix A.2.1. For analytical tractability and ease of presentation, we simplify slightly[I13] and use time-t notation:

$$\Pi_t(\Pi_t - \overline{\Pi}) = \beta E_t \left\{\Pi_{t+1}\left(\Pi_{t+1} - \overline{\Pi}\right)\right\} + \vartheta/\psi \left[\epsilon_t mc_t - (\vartheta\epsilon_t - 1)/\vartheta\right].$$

Here, $\epsilon_t := \exp\{\zeta_P\}$ is the unit-mean price-markup shock, $\vartheta > 1$ is the elasticity of demand, and $\psi > 0$ marks the price-adjustment costs. If the central bank targets inflation at $\overline{\Pi}$, clearly, the non-stochastic steady state of inflation is $\overline{\Pi}$. And, given the unitary steady-state of the markup shock, the non-stochastic steady-state of marginal costs is given by $mc = (\vartheta - 1)/\vartheta$.

Take unconditional expectations on both sides, so that

$$E\left\{\Pi_t(\Pi_t - \overline{\Pi})\right\} = \beta E \left\{\Pi_{t+1}\left(\Pi_{t+1} - \overline{\Pi}\right)\right\} + \vartheta/\psi \left[E\left\{\epsilon_t mc_t\right\} - (\vartheta E\left\{\epsilon_t\right\} - 1)/\vartheta\right].$$

[I13]We simplify here by having risk-neutral (owners of) firms, so that $Q(X, X') = \beta$. And we simplify by setting $y'/y = 1$.

Stationarity means that $E\left\{\Pi_t(\Pi_t - \overline{\Pi})\right\} = E\left\{\Pi_{t+1}\left(\Pi_{t+1} - \overline{\Pi}\right)\right\}$ so that

$$(1-\beta)\left[E\left\{\Pi_t^2\right\} - \overline{\Pi}E\left\{\Pi_t\right\}\right] = \vartheta/\psi\left[E\left\{\epsilon_t mc_t\right\} - (\vartheta E\left\{\epsilon_t\right\} - 1)/\vartheta\right].$$

Next, use that $E\left\{\epsilon_t mc_t\right\} = Cov(\epsilon_t, mc_t) + E\left\{\epsilon_t\right\}E\left\{mc_t\right\}$, where Cov marks the covariance. Also use that $E\left\{\epsilon_t\right\} = 1$. So that $(\vartheta E\left\{\epsilon_t\right\} - 1)/\vartheta = (\vartheta - 1)/\vartheta$. Recalling that $(\vartheta-1)/\vartheta = mc$, where mc marks the steady-state marginal costs, we have

$$(1-\beta)[E\{\Pi_t^2\} - \overline{\Pi}E\{\Pi_t\}] = \vartheta/\psi\left[Cov(\epsilon_t, mc_t) + E\{\epsilon_t\}E\{mc_t\} - mc\right].$$

The next steps use that $E\left\{\Pi_t^2\right\} = V(\Pi_t^2) + E\left\{\Pi_t\right\}^2$, where $V(\cdot)$ marks the variance. If the monetary policy rule is such that monetary policy ensures that inflation on average is at the target, as the text maintains, we have that $E\left\{\Pi_t\right\} = \overline{\Pi}$. Thus, $E\left\{\Pi_t^2\right\} = V(\Pi_t^2) + \overline{\Pi}^2$. With this, and using once more that $E\{\epsilon_t\} = 1$ and that $E\left\{\Pi_t\right\} = \overline{\Pi}$, we have that

$$(1-\beta)V\{\Pi_t^2\} = \vartheta/\psi\left[Cov(\epsilon_t, mc_t) + E\{mc_t - mc\}\right],$$

or, rearranging:

$$E\{mc_t - mc\} = -Cov(\epsilon_t, mc_t) + (1-\beta)\psi/\vartheta \cdot V\{\Pi_t^2\}.$$

Recalling that the markup is inversely related to marginal costs, this establishes the inverse link between inflation variability and the average markup. It also establishes a positive link between the average markup and the covariance of the markup shock with marginal costs as claimed in the main text.

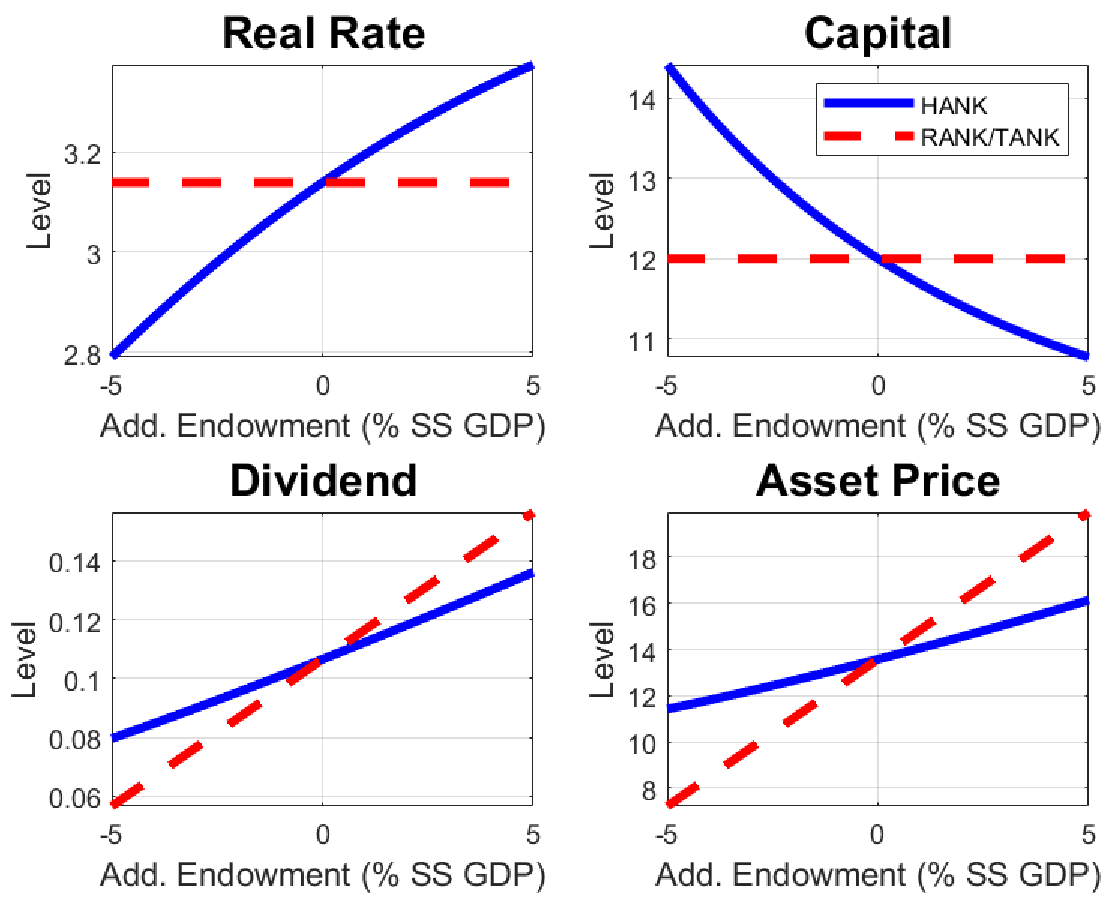
I.2 The effect of pure profits on the steady state

This appendix provides a quantitative version of Panel C. of Figure 2 in the main text. Namely, the appendix illustrates the effects that a rise in pure profits has in the HANK economy, and that the effects differ notably from those in RANK/TANK.

Focus on the non-stochastic steady state of the economy. Fix the parameters as calibrated in Section 3 in the main text. We wish to illustrate how an exogenous change in the supply of financial assets affects the steady state. We perform the following experiment. We solve for the steady state of the HANK economy. Then, keeping all other parameters fixed, we permanently add an exogenous, non-storable, per-period endowment to the resources of intermediate goods producers. In our model, this positive endowment is the same as a reduction in the fixed cost Ξ relative to our calibration. We solve for the new non-stochastic steady state that this change implies.[I14]

Figure I8 shows the resulting the non-stochastic steady state of the economy. The steady state in the HANK economy is shown by a solid blue line, the steady state in the RANK/TANK economies by a dashed red line.[I15]

Figure I8: Effect of changing firm's profits, in steady state



Notes: Effect of a change in profits on the steady state in HANK and RANK/TANK. See the text of this appendix for details.

[I14]We assume here that $\overline{y}$ in the wage rule does not change. Since y changes, the increased endowment leads to a modest change in wages, too. Assuming, instead, that wages remain entirely constant does not change the point we are making.

[I15]By the nature of the experiment, the effect on the steady state is identical in RANK and TANK.

The first panel on the top row shows the level of the real interest rate, the next the capital stock (as a multiple of quarterly GDP in the baseline), the bottom row shows dividends and the asset price (again scaled by the level of quarterly GDP in the baseline). In each of the panels, the y-axis shows the steady-state level of the variable, the x-axis shows the size of the endowment (as a percent of steady-state GDP in the baseline) that is allocated to producers. Thus, a value of 0 on the x-axis marks the steady state in the baseline economy. A positive value on the x-axis marks that the producers receive an endowment (having higher profits). A negative value means that the producers have a negative endowment (lower profits than in the baseline).

Let us first look at the RANK/TANK case (the dashed red line in each of the panels). In steady state, the real rate of interest remains unchanged if profits rise exogenously (top row, left panel): it is simply pinned down by the inverse of the discount factor (of savers). This is so for both the RANK model and the TANK model. As the real rate pins down capital accumulation, too, also the capital stock remains unchanged in RANK/TANK. That is, in both panels on the top row, the dashed line is horizontal. Dividends (bottom row, left) rise mechanically since the production sector has higher profits and is paying these out as additional dividends. For the same reason, the asset price rises, despite the constant real interest rate.

The effects are rather different in the HANK economy (the solid blue line in each of the panels). The dividend rises as the endowment increases (bottom row, left panel), which pushes up asset prices (bottom row, right panel). For a given real interest rate and capital stock, this increases the effective supply of financial assets. In HANK, savings demand is not infinitely elastic, however. Households save for a reason: for retirement, bequest, and precautionary savings. At a given real interest rate and level of the capital stock, households need to buy fewer shares so as to secure the same income stream as in the baseline. Therefore, to clear the asset market, the return on savings has to rise, driving up the real interest rate (top row, left panel). A higher real rate, in turn, drives up the required return on capital, resulting in a fall of the capital stock in the HANK economy (top row, right panel). In sum, with an exogenous increase in profits, in HANK dividends and asset prices still rise in the steady state, but by less than implied by the direct rise in the endowment (compare the solid "HANK" lines to the dashed "RANK/TANK" lines). Instead, the capital stock falls and the real rate rises. Both of these developments dampen the initial rise in the effective supply of financial assets.

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