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

Nils Gornemann† Keith Kuester ‡ Makoto Nakajima§

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Abstract

We build a New Keynesian business-cycle model with rich household heterogeneity. A central feature is that matching frictions render labor-market risk countercyclical and endogenous to monetary policy. Our main result is that a majority of households prefer substantial stabilization of unemployment even if this means deviations from price stability. A monetary policy focused on unemployment stabilization helps "Main Street" by providing consumption insurance. It hurts "Wall Street" by reducing precautionary saving and, thus, asset prices. On the aggregate level, household heterogeneity changes the transmission of monetary policy to consumption, but hardly to GDP. Central to this result is allowing for self-insurance and aggregate investment.

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†Board of Governors of the Federal Reserve System, International Finance Division, Washington, D.C. 20551, email: `nils.m.gornemann@frb.gov`

‡University of Bonn, Adenauerallee 24-42, 53113 Bonn, Germany, phone: +49-228 73-62195, email: `keith.kuester@uni-bonn.de`

§(corresponding author) Federal Reserve Bank of Philadelphia, Ten Independence Mall, Philadelphia, PA 19106-1574, email: `makoto.nakajima@phil.frb.org`

1 Introduction

Inequality in income and wealth is one of the defining features of our times (for example, Piketty 2014). Such inequality in income and wealth exposes some households to risks that others are not exposed to, creating the potential for sharp disagreement about business-cycle stabilization policies more generally, and monetary policy in particular. Exposure to labor-market risk seems one of the main dividing lines: Most working-age households barely have any financial income. For these "Main-Street" households labor-market risk is a central business-cycle risk; in contrast, wealthy "Wall-Street" households derive a substantial share of their income from financial or business sources.[1] This raises the question what the systematic response of monetary policy to the business cycle *should* look like in an unequal society, and how much disagreement there is. Filling this gap is the central goal of the current paper.

What sets the current paper apart from the literature is that it accounts for unemployment risk and its endogeneity to *systematic* monetary policy in an environment of substantial household heterogeneity. We believe that this is of central importance for being able to speak to the Federal Reserve's policy framework – and its dual mandate, in particular.

Toward this end, the current paper builds a New Keynesian sticky-price business cycle model. Nominal rigidities together with search and matching frictions in the labor market render labor-market risk countercyclical, and endogenous to monetary policy. Real wages are privately efficient but assumed to be rigid (as in Hall 2005), giving the monetary authority a reason to deviate from perfect price stability even absent heterogeneity (compare Blanchard and Galí 2010 and Ravenna and Walsh 2012). To this core we add rich household heterogeneity in order to replicate key features of the wealth and income distribution. Next to their wealth, households differ in their patience (as in Krusell and Smith 1998 and Carroll et al. 2015), productivity (as in Castañeda et al. 2003 and Nakajima 2012a), and employment status (as in Krusell et al. 2010). Financial markets are incomplete. Through a mutual fund, households hold precautionary savings against aggregate and idiosyncratic risk. Borrowing constraints mean that the cyclicality of labor-income risk matters for welfare. We show that the result is an economy that is neither approximated well with the saver-spender models of the business cycle (that follow Campbell and Mankiw 1989), nor is the representative-agent paradigm a good guide to its policy implications.

To the best of our knowledge our framework is the first that provides a global solution to a New Keynesian model with search and matching frictions, physical capital, self-insurance, and

[1] In the following, we will associate "Main Street" with the bottom 80 percent of the U.S. wealth distribution, whereas "Wall Street" are the top 5 percent. Compare the figures on income composition from the 2004 U.S. Survey of Consumer Finances documented in Table 6 in Appendix D.

rich household heterogeneity. We find substantial disagreement about monetary policy. This is so, even though we calibrate our model's baseline to a tranquil period (1984Q1 to 2008Q3).

The main result of the paper is that a large majority of households prefer a monetary policy focused on stabilizing unemployment even if this means that the central bank deviates from price stability. The median-wealth household's preferred monetary policy features twice as much inflation volatility as is present in the baseline calibration. Unemployment volatility, instead, is only a third as large as in the baseline (and as in the data). A policy that stabilizes unemployment makes the job-finding rate and, thereby, earnings risk less countercyclical. This reduces consumption risk particularly for those households that rely primarily on labor income and who risk hitting the borrowing constraint after an extended unemployment spell. We show that such a policy, while benefiting Main Street for the reasons spelled out above, hurts Wall Street. Wall Street suffer from the fall in asset prices that ensues as the middle class reduce their precautionary savings. In addition, Wall Street suffer from falling dividends due to increased costs of inflation variability to firms.

More in detail, these results emerge when we study the transition to a stronger response to unemployment in the central bank's interest-rate rule while keeping fixed the target levels for inflation and the unemployment rate in the rule as well as the response coefficient to inflation. While all households agree that there should be some response of monetary policy to unemployment in the interest-rate rule (as would a representative agent), they disagree about its size. The median-wealth household favors a response to unemployment that is twice as strong as the optimal response in the representative-agent ("RA") version of the model. The wealthiest 5 percent of households, instead, prefer a smaller response to unemployment than is optimal in the RA model.

The welfare results matter quantitatively: For the 0.1 percent wealthiest households implementing the median household's preferred policy instead of what they prefer means a welfare loss equivalent to 0.3 percent of *lifetime* consumption. More generally, welfare *losses* from more accommodative (that is, unemployment-focused) monetary policy are largest for those households that have ample savings and wish to dissave. In turn, consumption-equivalent welfare *gains* are largest for households that are income-rich but asset-poor, and so wish to accumulate savings. The welfare gains are largest for very highly-skilled households without savings, who would gain as much as an equivalent of 0.7 percent of *lifetime* consumption from a switch to the median-household's preferred monetary policy. Most households in our heterogeneous-agent ("HA") model have a positive target level of wealth (including impatient households with high skills). We show that, nevertheless, the median household would not favor policies that are optimal for a "representative" saver household. Nor is the median household content with policies aimed at "spenders" only. While a simpler Campbell and Mankiw (1989)-type saver-spender model would capture some of the trade-offs, it would fail to provide clear guidance as to the majorities in favor of the respective policies.

As regards business-cycle implications, we show that heterogeneity has a substantial impact on some of the macroeconomic aggregates. The changes in transmission are particularly pronounced for monetary policy shocks (shocks to the nominal interest rate), for which the consumption response doubles on impact. Overall, relative to the RA version of the model, consumption volatility in the HA model rises by 14 percent. At the same time, the volatility of GDP rises by much less than that of consumption, namely, by 4 percent. The key to understanding why increased consumption volatility does not translate one-for-one into increased output volatility lies with the very mechanism that makes consumption more volatile in the first place. The majority of households have positive savings. They cut back consumption in a recession partly for precautionary reasons, that is with a view toward saving. Households can save in the aggregate because both physical capital and the number of matches (employment relationships) are somewhat elastic (in-spite of adjustment costs). In the calibrated model, most of this increase in savings is channeled into aggregate investment. Aggregate investment, therefore, is less volatile in the HA model than the RA counterpart, explaining why the volatility of GDP does not rise one-for-one with that of consumption. A simpler saver-spender model in which households were either permanently excluded from asset markets or would, instead, not face any borrowing constraint would miss this mechanism.

Relation to the Literature

The model economy falls into the New Keynesian class of models of nominal rigidities, which replicate salient features of the business cycle (Smets and Wouters 2007), particularly if labor-market search and matching frictions are accounted for (Christiano et al. 2015). The New Keynesian literature has, to date, either focused on representative households or resorted to the fiction of a fixed set of households that are representative of their type. Among these papers, Galí et al. (2007) study the transmission of government spending shocks when some households are spenders/hand-to-mouth consumers (do not participate in asset markets). Drautzburg and Uhlig (2015) study fiscal stimulus in the Great Recession. In Iacoviello (2005) and Curdia and Woodford (2010), differences in preferences split households into borrowers and savers, the shares of each group being constant over time. Little work exists that links heterogeneity and labor-market frictions. An exception is Challe et al. (2013), who assume that all employed households join representative families. Upon entering unemployment, however, households leave the family with their share of the family's wealth. We, instead, do not resort to the fiction of a family nor to fixed types.

We build on incomplete-market general equilibrium models with infinitely lived agents and aggregate uncertainty and flexible prices. Krusell et al. (2010) and Nakajima (2012a) have introduced search and matching frictions into the framework and explored the effects of unemployment insurance. Doepke and Schneider (2006) and Meh et al. (2010), among others, focus on the wealth redistribution associated with surprise inflation under flexible prices, and Akyol (2004) and Erosa and Ventura (2002) on steady-state inflation. Albanesi (2007) studies the political economy of steady-state inflation. Recently, the literature has branched out to New Keynesian models. Werning (2015) provides analytical results that highlight the importance of countercyclical income risk, which in our model is generated by cyclical unemployment. McKay and Reis (2015) study the role of automatic stabilizers. They keep labor-market risk exogenous. Similarly, Guerrieri and Lorenzoni (2011) do not have a frictional labor market. McKay et al. (2015) study how borrowing constraints alter the efficacy of monetary forward guidance. Kaplan et al. (2016), Bayer et al. (2015), and Luetticke (2015) study the transmission of monetary policy shocks or other business-cycle shocks when nominal and real assets have different liquidity characteristics. While we assess a different mechanism through which monetary policy has distributional effects, what we share with their work is to demonstrate that simpler saver-spender models are not a good guide to the policy implications of heterogeneous-agent economies. Auclert (2015) finds that the redistribution channel is important for the transmission of monetary policy shocks to consumption. Sterk and Tenreyro (2016) study the redistribution channel when the government has nominal debt. Our paper, instead, abstracts from a portfolio composition decision and rather assumes that households can self-insure only through trading shares in a mutual fund that owns all the firms in the economy. We also abstract from modeling nominal portfolios altogether, building on the cashless limit of Woodford (1998). What sets the current paper apart is accounting for unemployment risk and its endogeneity to *systematic* monetary policy.

Another aspect sets the current paper apart: the solution approach. We show how to adapt the approximate-aggregation algorithm in Krusell and Smith (1998) and Reiter (2010) to the current setting. Solving the fully non-linear model allows us to make welfare comparisons. We document non-linearities in both the RA and HA variants of the model. This is in line with the non-linearities documented by Hairault et al. (2010) and Petrosky-Nadeau et al. (2015) in real model economies. Non-linearities are also central in den Haan et al. (2015), who entertain a heterogeneous-agent economy with labor-market search and matching frictions and money. There, nominal wage rigidity amplifies recessions if monetary policy fails to raise the money supply in the face of deflationary pressures. In our model, instead, we assume that monetary policy precludes amplification by following a standard Taylor rule. We show, however, that even within those confines monetary policy does have sizable distributional effects. Last, Ravn and Sterk (2012) study the effect of an exogenous increase in job uncertainty in a New Keynesian model with search and matching frictions and household heterogeneity. Next to the difference in focus, they entertain a much simpler environment without aggregate savings.

The rest of the paper is organized as follows. Section 2 introduces the model. Section 3 highlights the calibration and business-cycle implications of household heterogeneity. To lay the ground for the main result, section 4 highlights the effects of shocks on the aggregate economy and how they shape inequality. Section 5 discusses the welfare effects of one-time shocks and of a switch to more accommodative monetary policy. A final section concludes.

2 Model

The model economy is characterized by uninsurable income risk as in Krusell and Smith (1998). We follow Nakajima (2012a) and Krusell et al. (2010) and assume that the job-finding rate of unemployed households is linked to the state of the business cycle through Mortensen and Pissarides (1994) search and matching frictions. In equilibrium a recession will be a period of low job-finding rates and, endogenously, higher and – due to unemployment – more left-skewed earnings risk; compare the evidence in Guvenen et al. (2014). Households face market incompleteness and borrowing constraints. Therefore, they will be impacted differently by economic downturns, depending on their wealth and other characteristics. In addition, we assume nominal rigidities in price setting. This means that systematic monetary policy affects the shape of aggregate fluctuations and income risk.

2.1 States

We define the model in a recursive form. Define X as the vector of aggregate state variables at the time of production, where $X = (K, N, \zeta, \mu)$. K is the aggregate capital stock. N is aggregate employment. $\zeta = (Z, \zeta_R, \zeta_F)$ is the vector of aggregate shocks: an aggregate productivity shock, Z, a monetary policy (interest-rate) shock, ζ_R, and a financial "risk premium" shock, ζ_F. Smets and Wouters (2007) identify these three shocks as prominent sources of business-cycle fluctuations. Households are heterogeneous and characterized by four time-varying, idiosyncratic states (e, s, β, a). $e \in \{0, 1\}$ denotes employment status: $e = 1$ means a household is employed, $e = 0$

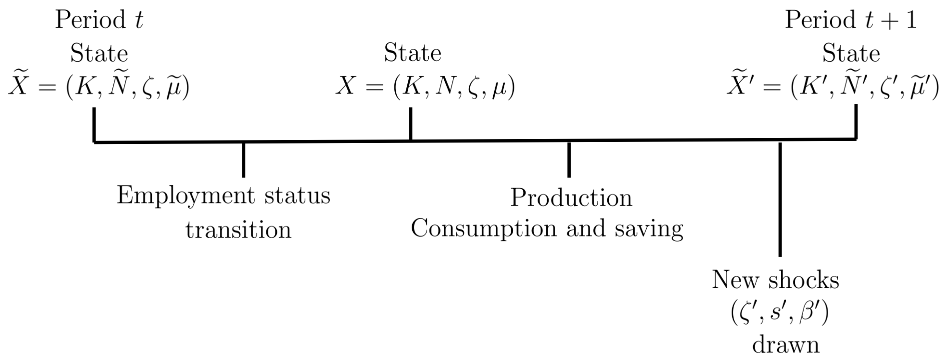


Figure 1: Timing of the model

means it is unemployed. While the job-loss probability will be taken as exogenous, following Shimer (2005) the job-finding rate of unemployed workers is determined endogenously.

We seek to investigate the implications for monetary policy of household income and wealth heterogeneity. We, therefore, have to capture key features of the wealth and income distribution in the U.S. economy. In order to match those, we introduce household heterogeneity in time preferences (as in Krusell and Smith 1998) and skills (as in Castañeda et al. 2003), both of which vary stochastically over time but are independent of the business cycle. $\beta \in B = \{\beta_L, \beta_H\}$ denotes the household's time-discount factor, where $0 < \beta_L < \beta_H < 1$. For each household, β follows a two-state first-order Markov process with transition matrix π_B. The probability of a transition from β to β' is given by $\pi_B(\beta, \beta')$. Household earnings are governed by the employment status and a household's skill level. Let $s \in S$ represent the skill level of a household. The skill follows an S-state first-order Markov process that is independent of the aggregate state. Denoting the transition matrix by π_S, the probability of a transition from s to s' is $\pi_S(s, s')$. The skill transitions mean that higher-skilled households seek to self-insure not only against business-cycle risk and the risk of job loss, but also against a fall in earnings ability. Many households would, thus, accumulate precautionary savings even if there were no business-cycle risk.[2] Households can save by investing in a representative mutual fund that owns all firms in the economy. $a \in A \subseteq \mathbb{R}$ denotes the share holdings of a household. $\mu(e, s, \beta, a)$ is the type distribution of households.

2.2 Timing

The timing is shown in Figure 1. Aggregate shocks and shocks to households' skill levels and time preferences are drawn at the beginning of a period and become known immediately. Denote

[2] We entertain heterogeneity in both β and s to match the wealth and income distribution in a calibration where unemployment is costly to the household. We could have dropped heterogeneity in β if we had opted for a smaller surplus from employment. Indeed, this is what we did in an earlier version of the paper.

by $\widetilde{\mu}$ and $\widetilde{N}$ the type distribution and aggregate employment, respectively, before labor-market transitions have occurred. Let $\widetilde{X} = (K, \widetilde{N}, \zeta, \widetilde{\mu})$ denote the corresponding state of the economy. Employed households lose their jobs with exogenous probability λ. Then firms post vacancies. All unemployed households search for jobs. Matching takes place and the aggregate state becomes $X = (K, N, \zeta, \mu)$. Thereafter, the remaining decisions are made and production takes place.

2.3 Households

Preferences are time-separable with a period utility function given by $u(c) = c^{1-\sigma}/(1-\sigma)$. We first describe the problem of a household that is employed after the employment transitions have taken place ($e = 1$) and has skill level s, time preference β, and asset holdings a. The household's Bellman equation is given by

$$W(X, 1, s, \beta, a) = \max_{c, a' \geq 0} \Big\{ u(c) + \beta \mathbb{E} \Big[\Big(1 - \lambda + \lambda\, f(\widetilde{X}')\Big)\, W(X', 1, s', \beta', a') + \lambda \Big(1 - f(\widetilde{X}')\Big)\, W(X', 0, s', \beta', a') \Big] \Big\}$$

$$\text{s.t.} \qquad c + p_a(X) a' = \big(p_a(X) + d_a(X)\big) a + w(X) s \big(1 - \tau(X)\big),$$

The household chooses consumption, c, and the number of shares it wants to carry into the next period, $a' \geq 0$, so as to maximize expected lifetime utility subject to its budget constraint. The household takes the job-finding rate, $f(\widetilde{X}')$, the ex-dividend price of shares, $p_a(X)$, dividends, $d_a(X)$, the wage, $w(X)$, and the payroll tax rate, $\tau(X)$, as given. The expectation operator $\mathbb{E}$ is conditional on the distribution of aggregate and individual shocks going forward (ζ', s', β'). The household takes the laws of motion of the aggregate states, $\widetilde{X}' = \widetilde{G}(X)$ and $X' = G(X)$ as given. Next period, the household will keep its current job with exogenous probability $1 - \lambda$. If the household loses the job, it searches for employment. Its search intensity is constant. With probability $f(\widetilde{X}')$ the household will find a new job immediately and be employed (at a new firm). Otherwise, the household's employment status changes to $e = 0$ and the household will go through a spell of unemployment. This happens with probability $\lambda(1 - f(\widetilde{X}'))$. Turning to the budget constraint, the household uses the resources it has available for consumption, c, and for purchasing shares that it carries into the next period, $p_a(X)a'$. The household's resources (right-hand side of the budget constraint) are composed of the *ex-dividend* value of the shares that the household owns at the beginning of the period, $p_a(X)a$, dividends associated with the shares, $d_a(X)a$, and after-tax labor income, $w(X)s(1 - \tau(X))$. Here $w(X)$ is the real wage per efficiency unit and $\tau(X)$ is a proportional labor-income tax rate.

If the household is unemployed after the employment transitions have taken place, its Bellman equation is

$$W(X,0,s,\beta,a) = \max_{c,a'\geq 0} \Big\{ u(c) + \beta \mathbb{E}\Big[f(\widetilde{X}')W(X',1,s',\beta',a') + \Big(1 - f(\widetilde{X}')\Big) W(X',0,s',\beta',a') \Big] \Big\}$$

$$\text{s.t.} \qquad c + p_a(X)a' = (p_a(X) + d_a(X))\, a + b(s).$$

This reflects the fact that next period the unemployed household will move into employment with state-dependent probability $f(\widetilde{X}')$ or will otherwise remain unemployed. Instead of wage income, the unemployed receive unemployment benefits, $b(s)$. Benefits depend on a household's skills in order to introduce in a parsimonious way that the benefits depend on past earnings.

For future reference, denote the resulting optimal decision rules for consumption and share holdings by $c = g_c(X, e, s, \beta, a)$ and $a' = g_a(X, e, s, \beta, a)$, respectively.

2.4 Mutual Fund

We abstract from a portfolio choice by the individual households. Households delegate financial management to a representative mutual fund, that is, they own all their wealth through equity claims on the fund. There are five types of assets in the economy. Only the mutual fund trades these: equity of producers of final goods, of intermediate goods, of capital services, and of labor services, plus one-period nominal bonds.

Firms are owned by the mutual fund and make decisions so as to maximize their market value. Intermediate goods firms and capital services firms face dynamic decision problems. We follow Favilukis (2013) and assume that the mutual fund prices claims based on the asset-weighted average of its shareholders' period-to-period valuation. Letting $u_c(c)$ mark the marginal utility of consumption, in shorthand notation the discount factor the funds apply is

$$Q(X, X') = \int_{\mathcal{M}} a'\beta \frac{u_c(c')}{u_c(c)}\, d\mu'.$$

The above is shorthand for the exact formula shown in Appendix A.[3]

We abstract from modeling public-sector debt or money. Instead, we use the cashless limit assumption (Woodford, 1998) commonly used in New Keynesian models. The central bank

[3] Other papers do not need to specify the discount factor. In Krusell and Smith (1998) households invest directly in capital and firms only have static rental decisions to make. In den Haan et al. (2015) there are only labor firms. They only make one decision (to post a vacancy or not). Neither paper has sticky prices. See Carceles-Poveda and Coen-Pirani (2010) for results regarding investor unanimity with heterogeneous households.

controls the rate of return on risk-free nominal private-sector bonds. Since prices are sticky, by setting the nominal interest rate, the central bank influences the expected real rate of return on the nominal bonds and, in effect, the return on all other assets in the economy. Denote by $\Pi(X)$ the gross rate of inflation. Equilibrium in the bond market requires that all assets be priced according to the mutual fund sector's discount factor. This, for the bond investment decision, yields a standard Euler equation (for the mutual fund rather than a household)

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

Firms transfer their profits to the mutual fund, which, in turn, distributes profits to households in the form of dividends. Since we still need to introduce some notation, we report the exact expression for dividends per share, $d_a(X)$, only in equation (9) further below.

2.5 Producers of Intermediate Goods

There is a unit mass of firms that produce differentiated intermediate goods. An intermediate good producer $j \in [0,1]$ buys labor and capital services l_j and k_j at the competitive rates $h(X)$ and $r(X)$, respectively. The producer sells its output to final goods firms under monopolistic competition at price P_j. In the following, let $X_p := (X, \mu_p)$ be state X augmented by the distribution across firms of last period's prices, $P_{j,-1}$. There are nominal rigidities: Price adjustment is subject to Rotemberg (1982)-type quadratic adjustment costs. The producer's value is:

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

$$\text{s.t.} \quad y_j(X,P_j,P) = \left(\frac{P_j(X_p)}{P(X_p)}\right)^{-\epsilon} y(X), \tag{1}$$

$$y_j(X,P_j,P) = Z k_j^{\theta} \ell_j^{1-\theta}, \tag{2}$$

where $y_j(X,P_j,P)$ is firm j's output and $y(X)$ is the aggregate output of the final good. $P(X_p)$ is the aggregate price level. Constraint (1) is the firm's demand function, $\epsilon > 1$. Equation (2) is the production function of intermediate good j. $\Xi \geq 0$ is a fixed cost of production. Parameter $\psi > 0$ indexes the extent of nominal rigidities. $\overline{\Pi}$ takes on a fixed value.

Letting $\overline{Z}$ be steady-state total factor productivity (TFP), TFP itself evolves according to:

$$\log(Z') = (1-\rho_Z)\log(\overline{Z}) + \rho_Z \log(Z) + \epsilon'_Z, \text{ where } \epsilon_Z \text{ is i.i.d. } N(0,\sigma_Z^2), \rho_Z \in [0,1).$$

The financial shock, ζ_F, drives a wedge between the firm's evaluation of future profits and the mutual fund's. This shock, which leads to impulse responses similar to the risk-premium shock of Smets and Wouters (2007), pertains to equity investments only. We assume that

$$\log(\zeta'_F) = \rho_{\zeta_F} \log(\zeta_F) + \epsilon'_{\zeta_F}, \text{ where } \epsilon_{\zeta_F} \text{ is i.i.d. } N(0,\sigma_{\zeta_F}^2), \rho_{\zeta_F} \in [0,1).$$

If their prices last period are identical, in equilibrium all intermediate good producers will set the same price this period as well. The optimal behavior of these firms can then be described by the current aggregate rate of *inflation,* $\Pi(X)$, and other contemporaneous aggregate variables or the expectations of each of these. This means past prices, $P_{j,-1}$, are not state variables. Each producer j faces the same marginal costs and chooses the same amount of labor and capital inputs, so $k_j = k(X)$ and $l_j = l(X)$. Next, we turn to the production of these inputs.

2.6 Producers of Capital Services

There is a representative capital-producing firm, the value of which is

$$J_K(X,K) = \max_{v,i,K'} \left\{ r(X)Kv - i + \mathbb{E}\left[\zeta_F Q(X,X') J_K(X',K')\right] \right\} \tag{3}$$

$$\text{s.t.} \qquad K' = \big(1-\delta(v)\big)K + \zeta\left(\frac{i}{K}\right)K. \tag{4}$$

The capital-producing firm produces homogeneous "capital services." It sells these to the intermediate goods sector at the competitive rate $r(X)$. Capital services are the product of the capital stock, K, and the utilization rate of capital, v. The rate of depreciation of capital, $\delta(v)$, increases with utilization. The functional form follows Greenwood et al. (1988), namely,

$$\delta(v) = \delta_0\, v^{\delta_1},\ \delta_0 > 0,\ \delta_1 > 1.$$

Capital producers decide how much to invest in next period's capital stock, K'. Due to capital adjustment costs, capital investment (i) does not translate one-to-one into new capital. We follow Jermann (1998) by specifying the functional form of these adjustment costs as

$$\zeta\left(\frac{i}{K}\right) = \zeta_0 \left(\frac{i}{K}\right)^{1-\zeta_1} + \zeta_2.$$

The problem of the capital-producing firm characterizes aggregate investment $i(X)$, the aggregate utilization rate $v(X)$, and the aggregate capital stock next period $K'(X)$.

2.7 Producers of Labor Services

Labor agencies produce homogeneous "labor services." Labor agencies may be matched with exactly one household or they are not matched. The value of a matched labor agency is

$$J_L(X,s) = \big(h(X) - w(X)\big)s + \mathbb{E}\big[\zeta_F Q(X,X')(1-\lambda)J_L(X',s')\big].$$

The labor agency produces an amount s of labor services, where s is the skill level of the household it employs. Labor services are sold at competitive rate $h(X)$. Wage payments are indexed by the skill level. Last, the continuation value reflects the fact that only with probability $(1-\lambda)$ will the match between a labor agency and its household be producing in the next period. Otherwise, the match will be dissolved. The exposition here anticipates that due to free entry, the value of a labor agency not matched to a household is zero.

Employment is subject to search and matching frictions. As a result, there is a wide range of wages that are bilaterally efficient and can, thus, arise in equilibrium. In line with assumptions found elsewhere in the New Keynesian literature, for example, in Blanchard and Galí (2010), we postulate that the wage evolves according to

$$\log w(X) - \log \overline{w} = \epsilon_w \cdot \left[\log\left(\frac{GDP(X)}{N(X)}\right) - \log\left(\frac{\overline{GDP}}{\overline{N}}\right)\right]. \tag{5}$$

Above, $\overline{w}$ is the steady-state wage level. The wage reacts to labor productivity, $GDP(X)/N(X)$. Here gross domestic product, $GDP(X)$, is defined as production, $y(X)$, net of price adjustment costs and fixed costs, both of which we see as intermediate inputs. That is,

$$GDP(X) := y(X) - \Xi - \frac{\psi}{2}(\Pi(X) - \overline{\Pi})^2 y(X).$$

Parameter $\epsilon_w \in [0,1]$ in (5) represents the elasticity of the wage with respect to measured labor productivity. Values of $\epsilon_w < 1$ can be interpreted as reflecting "wage stickiness," which serves to amplify labor-market fluctuations, as in Shimer (2004) and Hall (2005).[4]

Labor agencies not yet matched to a household can post a vacancy at cost κ. Labor firms cannot target their vacancies at households with specific individual characteristics. The following free-entry condition governs the number of vacancies in equilibrium:

$$\kappa = \frac{M(\widetilde{X}, V)}{V} \int_{\mathcal{M}} J_L\left(\hat{G}(\widetilde{X}), s\right) d\mu.$$

Here $X = \hat{G}(\widetilde{X})$ characterizes the law of motion for $\widetilde{X}$. Vacancies will be created up to the point where the cost of creating a vacancy (left-hand side) just balances the expected gain (right-hand side). The latter is determined by the product of the expected value of a match to the firm, and the probability that an individual vacancy will be filled. The job-filling probability is the ratio of the aggregate mass of new matches, M, to the aggregate mass of vacancies, V. Matches form according to the following matching function:

$$M(\widetilde{X}, V) = \frac{\left(U(\widetilde{X}) + \lambda N(\widetilde{X})\right) V}{\left(\left(U(\widetilde{X}) + \lambda N(\widetilde{X})\right)^{\alpha} + (V)^{\alpha}\right)^{\frac{1}{\alpha}}}, \quad \alpha > 0. \tag{6}$$

Here $U(\widetilde{X}) + \lambda N(\widetilde{X})$ is the measure of households searching for a job (remember the timing assumption discussed in Section 2.2). Matching function (6), taken from den Haan et al. (2000), ensures that job finding and job filling rates are always well-defined probabilities. All households without a job have the same job finding rate, namely,

$$f(\widetilde{X}) = \frac{M(\widetilde{X}, V(\widetilde{X}))}{U(\widetilde{X}) + \lambda N(\widetilde{X})}.$$

2.8 Producers of the Final Good

Final goods can be used for consuming, investing, facilitating price adjustment, and creating vacancies. There is a representative competitive final good firm. It transforms the differentiated intermediate goods y_j, $j \in [0, 1]$, into a homogeneous output good, taking the input prices $P_j(X_p)$

[4] We have verified that during all simulations of the model and at all grid points used in the model solution neither the household nor the labor agency would prefer to terminate a match.

as given. The problem of the representative final good producer is

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

The optimal decision translates into the demand function anticipated in (1).

2.9 Central Bank and Fiscal Authority

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

$$\log\left(\frac{R(X)}{\overline{R}^{\text{CB}}}\right) = \phi_\Pi \log\left(\frac{\Pi(X)}{\overline{\Pi}^{\text{CB}}}\right) - \phi_u \left(U(X) - \overline{U}^{\text{CB}}\right) + \zeta_R, \tag{7}$$

where $U(X) = 1 - N(X)$ is the unemployment rate at the end of the period. All else equal, the central bank thus raises the nominal rate above $\overline{R}^{\text{CB}}$ whenever inflation exceeds the inflation target of $\overline{\Pi}^{\text{CB}}$ (parameter $\phi_\Pi > 1$) and when the unemployment rate is lower than its target value $\overline{U}^{\text{CB}}$ (parameter $\phi_u \geq 0$). The superscripts "CB" here signal that these are target values given to the central bank. There are persistent monetary policy shocks, ζ_R, that capture deviations from typical behavior, with

$$\log(\zeta_R') = \rho_{\zeta_R} \log(\zeta_R) + \epsilon_{\zeta_R}\ , \quad \text{where } \epsilon_{\zeta_R} \text{ is i.i.d. } N(0, \sigma^2_{\zeta_R})\ , \rho_{\zeta_R} \in [0,1).$$

The fiscal authority runs a balanced-budget policy so that

$$\int_{\mathcal{M}} \mathbb{1}_{e=0}\, b(s)\ d\mu = \tau(X) \int_{\mathcal{M}} \mathbb{1}_{e=1}\, w(X)s\ d\mu. \tag{8}$$

The government pays unemployment benefits $b(s)$ for an unemployed household of skill s ($\mathbb{1}$ marks the indicator function). This is financed by a proportional tax $\tau(X)$ on the labor income of employed households.[5]

2.10 Aggregate Laws of Motion

Next, we discuss how to construct the aggregate law of motion. For expositional purposes, we use two sets of aggregate state vectors, $\widetilde{X}$ and X, that differ in time of measurement (at the beginning of the period and at the end of the period, respectively); compare Section 2.2. We therefore have three types of laws of motion, $X' = G(X)$, $\widetilde{X}' = \widetilde{G}(X)$, and $X = \hat{G}(\widetilde{X})$. Let us

[5] The proportional tax reduces the labor income of employed households, yet does not distort their labor supply decisions (search effort is assumed to be exogenous) nor firms' hiring decisions (because of the wage rule).

focus on one element of X at a time.

First, installed capital K does not change during a period. It therefore does not differ between $\widetilde{X}$ and X, so we only need one law of motion for K; compare equation (4):

$$K'(X) = \big[1 - \delta\big(v(X)\big)\big]\, K + \zeta\left(\frac{i(X)}{K}\right) K$$

where $v(X)$ and $i(X)$ are obtained from the optimization problem of the capital-producing sector. Next, the law of motion for employment during the production stage of this period is given by

$$N(X) = (1 - \lambda)N(\widetilde{X}) + M(\widetilde{X}, V(\widetilde{X})).$$

Since there are no labor-market transitions at the end of the period, employment at the beginning of the next period coincides with employment at the end of the current period: $N'(\widetilde{X}') = N(X)$. Last, we need to keep track of the type distribution of households. Remember that, at the beginning of a period, the type distribution is $\widetilde{\mu}(\widetilde{e}, s, \beta, a)$, where $\widetilde{e}$ is the employment status *before* the separations and hiring occur. The type distribution during the period (after the transitions in employment status) is $\mu(e, s, \beta, a)$. $\widetilde{\mu}$ and μ are linked as follows:

$$\begin{aligned} \mu(1, s, \beta, a) &= f(\widetilde{X})\widetilde{\mu}(0, s, \beta, a) + [1 - \lambda + \lambda f(\widetilde{X})]\, \widetilde{\mu}(1, s, \beta, a), \\ \mu(0, s, \beta, a) &= [1 - f(\widetilde{X})]\widetilde{\mu}(0, s, \beta, a) + \lambda[1 - f(\widetilde{X})]\, \widetilde{\mu}(1, s, \beta, a). \end{aligned}$$

Notice that, from $\widetilde{\mu}$ and μ, only the employment status changes. The transition between the type distribution at the end of the period, μ, and the type distribution at the beginning of the next, $\widetilde{\mu}'$, is characterized by

$$\widetilde{\mu}'(\overline{e}, \overline{s}, \overline{\beta}, \overline{A}) = \sum_{s \in S} \pi_S(s, \bar{s}) \sum_{\beta \in B} \pi_B(\beta, \bar{\beta}) \int_{\mathcal{M}} \mathbb{1}_{e=\overline{e}}\, \mathbb{1}_s\, \mathbb{1}_\beta\, \mathbb{1}_{g_a(X, \overline{e}, s, \beta, a) \in \bar{A}}\; d\, \mu(e, s, \beta, a),$$

with $\overline{A} \in A$ being a subset of the space of the share holdings and $\overline{e}$, $\overline{s}$, $\overline{\beta}$ being individual states in $\{0, 1\}$, S, and B respectively. $\pi_S(s, \overline{s})$ marks the probability to transit from skill state s to state $\overline{s}$ at the end of the period. $\pi_B(\beta, \bar{\beta})$ is the corresponding transition probability for a household's time-preference parameter.

2.11 Market Clearing and Equilibrium

Six types of markets open in the model: markets for final goods, intermediate goods, labor services, capital services, shares of the mutual fund, and financial markets on which the mutual fund trades. The final goods market clears if

$$y(X) = \int_{\mathcal{M}} g_c(X, e, s, \beta, a)\; d\mu + i(X) + \kappa V(\widetilde{X}) + \int_0^1 \left[\Xi + \frac{\psi}{2} \left(\frac{P_j}{P_{j,-1}} - \overline{\Pi} \right)^2 y(X) \right]\; dj,$$

where the terms on the right-hand side are aggregate consumption, investment, the vacancy posting costs and price adjustment costs, respectively. The markets for all intermediate goods clear whenever $y(X) = Z k_j^{\theta} \ell_j^{1-\theta}, \forall\, j \in [0, 1]$,

The market for labor services clears if $\int_{\mathcal{M}} s \mathbb{1}_{e=1}\; d\mu = \int_0^1 \ell_j\; dj$, The market for capital services clears if $v(X)K = \int_0^1 k_j\; dj$; the market for shares of the mutual funds if $\int_{\mathcal{M}} g_a(X, e, s, \beta, a)\; d\mu = 1$. Dividends are given by

$$\begin{aligned} d_a(X) \quad = \quad & \textstyle\int_0^1 \left[y_j(X) \frac{P_j(X)}{P(X)} - r(X) k_j(X) - h(X) \ell_j(X) - \Xi - \frac{\psi}{2} \left(\frac{P_j}{P_{j,-1}} - \overline{\Pi} \right)^2 y(X) \right]\; dj \\ + \quad & r(X) K(X) v(X) - i(X) + \textstyle\int_{\mathcal{M}} (h(X) - w(X)) s\; d\mu - \kappa V(\widetilde{X}). \end{aligned} \tag{9}$$

The first line is the profits in the intermediate goods sector, the second line profits in the capital services and labor services sectors net of investment in capital and vacancies, respectively.

Last, the financial markets on which the mutual fund trades clear when all firms are held by the mutual fund and inside bonds are in zero net supply. For a formal definition of recursive equilibrium, see Appendix B.

3 Calibration

The model is solved numerically using a solution method that is adapted from Krusell and Smith (1998) and Reiter (2010). Our solution algorithm, described in detail in Appendix C, takes non-linearities and uncertainty in both aggregate and idiosyncratic dynamics into account.

We calibrate the model to the U.S. economy, one period being a quarter. The calibration sample is 1984Q1 to 2008Q3. Several parameters are set such that the steady state in the model without aggregate shocks ("steady state" henceforth) matches long-run averages in the data. Other parameters are set with a view toward targeting second moments in the data. The latter set of parameters are chosen to match the second moments in the representative-agent ("RA" henceforth) counterpart of our heterogeneous-agent model ("HA" henceforth). Given the numerical burden of the solution algorithm used to solve the HA model, we do not use the simulated method of moments to directly match the heterogeneous-agent model to long-run moments.[6] In this context, we choose the systematic response of monetary policy to unemployment (ϕ_u), the investment adjustment cost parameter (ζ_1), and the volatilities of the financial and TFP shocks to jointly match the volatility of HP-filtered log inflation, unemployment, output, and consumption. We target consumption volatility, because this is of direct relevance for welfare. Tables 1 and 2 summarize the values we choose for the calibrated parameters. We will discuss these choices next.

Table 1: Calibrated Parameters

Households		Capital services		Ξ	0.303	$\overline{R}^{\text{CB}}$	1.015
σ	1.5	ζ_0	0.721	Labor market		ϕ_Π	1.500
$\pi_B \beta, \beta'$	Table 2	ζ_1	0.104	λ	0.100	ϕ_u	0.107
β_L	0.849	ζ_2	–0.0017	α	1.716	Shocks	
β_H	0.993	δ_0	0.015	$\overline{w}$	0.670	ρ_{ζ_R}	0.800
$\pi_S s, s'$	Table 2	δ_1	1.673	ϵ_w	0.450	$\sigma_{\zeta_R} * 100$	0.0625
s_1	0.341	Intermediate goods		κ	0.249	ρ_{ζ_F}	0.800
s_2	0.778	ϵ	3.00	Monetary policy		$\sigma_{\zeta_F} * 100$	0.135
s_3	1.774	θ	0.231	$\overline{\Pi}^{\text{CB}}$	1.005	ρ_Z	0.950
s_4	9.158	ψ	38.08	$\overline{u}^{\text{CB}}$	0.057	$\sigma_Z * 100$	0.576
		$\overline{\Pi}$	1.005			$\overline{Z}$	0.843

Notes: The table shows the calibrated parameters. The main text explains the calibration targets.

3.1 Households

We set the coefficient of relative risk aversion to $\sigma = 1.5$, as, for example, in Castañeda et al. (2003). The parameters that we calibrate next are those that pertain to the heterogeneity in skills and time preferences. This heterogeneity allows us to match key moments related to earnings risk and the wealth distribution. We assume that the time-preference parameter β follows a two-state first-order Markov process with values β_L and β_H. Skills s follow a four-state first-order Markov process. Time preferences and skills are independent of the business cycle. We parameterize the time-discount factor and the skill process by ensuring that in the steady state the model meets the following targets: (i) the Gini index of wealth is 0.81; (ii) the wealth-poorest 30 percent of households have a total net worth of 0; (iii) the standard deviation of residual earnings of continuously employed workers is 0.19;[7] (iv) the autocorrelation of residual earnings of continuously-employed workers is 0.95; (v) 1 percent of the households are much more skilled than the rest ("super-skilled," see below); and (vi) the probability of remaining a

[6] The RA model has $\beta = 0.99$ so as to match the same steady-state real rate as in the HA model.

[7] The value is taken from Krueger et al. (2015), who estimate an AR(1) process for residual labor earnings after removing age, education, and time effects.

super-skilled worker is 0.97. Targets (i) and (ii) are derived using the 2007 Survey of Consumer Finances. The values of targets (iii) and (iv) are taken from Krueger et al. (2015) and capture persistent idiosyncratic shocks to earnings conditional on staying employed. Targets (v) and (vi) are based on the discussion in Nakajima (2012b) on how to calibrate an income process with super-skilled households.

For the time-discount factor, β, we impose two additional targets: a real rate of return of 4 percent in the steady state and we calibrate the transition matrix such that each household redraws its discount factor on average every 40 years and has an equal chance of drawing each of the two in this event. The idea follows Krusell and Smith (1998) and aims to capture intergenerational changes in the saving behavior of dynasties. This results in values $\beta_L = 0.849$ and $\beta_H = 0.993$ and the transition matrix shown in the left matrix of Table 2. For the income

Table 2: Transition Probabilities

Time-discount factor, $\pi_B(\beta, \beta')$

today \ tomorrow	β_L	β_H
β_L	0.9969	0.0031
β_H	0.0031	0.9969

Skills, $\pi_S(s, s')$

today \ tomorrow	s_1	s_2	s_3	s_4
s_1	0.9463	0.0528	0.0007	0.0002
s_2	0.0264	0.9470	0.0264	0.0002
s_3	0.0007	0.0528	0.9463	0.0002
s_4	0.0069	0.0069	0.0069	0.9793

Notes: Transition probabilities per quarter. Left: $\pi_B(\beta, \beta')$. Right matrix: $\pi_S(s, s')$. s_1 : lowest skill group, s_4 : highest skill group. Rounding for the table means rows may not sum to 1.

process we use four discrete skill levels. s_1 is the lowest skill level, s_2 a medium skill level, and s_3 a high skill level. The fourth skill level, s_4, is used to capture vastly more productive households, the "super-skilled." We parameterize the skill transitions as follows. Skill transitions are independent of the business cycle (and of employment). The process of transitions between the lower three skill levels is assumed to be governed by a discretized AR(1) process for the log of individual productivity with mean zero, persistence ρ_s and variance of the innovation σ_s^2. We discretize using the algorithm described in Rouwenhorst (1995). For the transitions to or from the super-skilled state, we assume that the probability of becoming super-skilled is the same for each normal skill level. Similarly, a household that loses its super skills is equally likely to transition into either of the three "normal" skill levels. With these assumptions, there are three sets of parameters associated with the super-skilled state: the probability of staying super-skilled, π_{s_4,s_4}, the probability that a "normal" household becomes super-skilled, $\pi_{s_1,s_4} = \pi_{s_2,s_4} = \pi_{s_3,s_4}$, and the productivity of the super-skilled, s_4. Table 2 reports the resulting transition probabilities per quarter.

Figure 13 in Appendix D shows that the calibrated model closely matches the wealth distribution in the U.S. economy. In the same appendix, Table 6 shows that the model matches the main feature originating from this observation, namely, that "Wall Street" (the 5 percent wealthiest households) derive a large share of income from financial wealth, whereas "Main Street" (the remaining 95 percent) does not.

3.2 Producers of Capital Services

We set the curvature parameter of capital adjustment costs to $\zeta_1 = 0.104$. We require the steady state with adjustment costs to be the same as the one without such costs. This determines the remaining parameters for capital adjustment. The resulting values are shown under "Capital services" in Table 1. Furthermore, we require that the utilization rate of capital be unity in the steady state and that the steady-state depreciation rate be 6 percent per year. This pins down parameters δ_0 and δ_1.

3.3 Producers of Intermediate Goods

We set the fixed costs Ξ so as to generate a steady-state profit share in GDP of intermediate good producers of 3 percent. θ, the exponent of capital in the production function, is calibrated to deliver a quarterly capital to GDP ratio of 8. The parameter ψ governs the price adjustment cost. We set it to 38.08. If we were to linearize the Phillips curve (we do not), the slope of the Phillips curve thus implied would be equal to that of a Calvo-Yun-type New Keynesian Phillips curve (without strategic complementarities) when prices lasted for 5 quarters on average given our choice of the elasticity of substitution. This matches the slope of the Phillips curve as commonly estimated, for example, in Galí and Gertler (1999). We set the reference level of inflation to $\overline{\Pi} = 1.005$, meaning firms index their prices to an inflation rate of 2 percent per year. We set the elasticity of substitution across intermediate goods to $\epsilon = 3$, implying a steady-state markup of 50 percent.[8] A low value for the elasticity allows us to calibrate a relatively small price-adjustment cost ψ. This choice makes the model numerically more stable in the presence of persistent deviations of inflation from target, since a smaller share of output is used to cover the adjustment costs in states with large price changes. It thereby allows us to entertain a wide range of parameters of the monetary policy rule, and in particular such parameters that induce more volatile inflation.

[8] The range of values for this parameter used in the literature is fairly wide. See, for example, Kuester (2010) and Midrigan (2011) for references.

3.4 Labor Market

The value for the separation rate $\lambda = 0.10$ is consistent with the JOLTS data. We set the elasticity of the matching function with respect to the number of searchers so as to have a steady-state unemployment rate of 5.7 percent. This results in a value of $\alpha = 1.716$. Following den Haan et al. (2000), in the model's steady state we assume a quarterly vacancy-filling rate of 0.71. Using the steady-state free-entry condition, this yields a vacancy posting cost of $\kappa = 0.249$. Any wage that leaves both the matched labor-services firm and the household with a positive surplus from continuing the match will be an equilibrium wage. We parameterize wage equation (5) as follows. Following Hagedorn and Manovskii (2008), we target an elasticity of wages with respect to productivity of $\epsilon_w = 0.45$. We set the steady-state wage per efficiency unit of labor to $\overline{w} = 0.670$. This generates a labor share of 63 percent. The wage stays in the bargaining set in all the simulations reported in the paper.

3.5 Central Bank

The inflation target ($\overline{\Pi}^{\text{CB}}$) is set such that the model implies a steady-state inflation rate of 2 percent annualized, in line with the Federal Reserve System's inflation objective. The rate $\overline{R}^{\text{CB}}$ used in the Taylor rule (7) is chosen to deliver a target for the steady-state real rate of return of 4 percent. The response of the policy rate to inflation in the Taylor rule is set at $\phi_\Pi = 1.5$ as in Taylor (1993). The response parameter to unemployment is set to $\phi_u = 0.107$. The target level for the unemployment rate, $\overline{U}^{\text{CB}}$, is set to the steady-state level of unemployment (0.057).

3.6 Fiscal Authority

The unemployment benefit system mimics the system in place in the U.S. in that the replacement rate is assumed to be 40 percent of the steady-state wage (as in Shimer 2005) for the lower skill groups. Benefits are capped at 40 percent of the mean earnings in the economy. That is, $b(s) = \min(b \cdot s \cdot \overline{w}, b \cdot$ economy-wide average earnings in steady state). The payroll tax rate is set so as to balance the budget on a period-by-period basis. The choices above imply a steady-state payroll tax rate of 2.42 percent.

3.7 Shocks

The steady-state level of the TFP shock, $\overline{Z}$, is chosen so as to normalize steady-state GDP to unity. The persistence of the TFP shock is $\rho_Z = 0.95$. The standard deviation of the TFP shock ($\sigma_Z = 0.0058$) was calibrated such that GDP in the RA version of the model (once HP-filtered) has the same standard deviation as HP-filtered GDP in the data. The persistence of the monetary policy shock, $\rho_D = 0.8$, was chosen so as to have persistence of the real rate after a monetary policy shock. Its standard deviation, σ_D, is calibrated to 0.000625, so that the annualized size of a typical monetary policy shock is 6.25 basis points (25 basis points annualized), the typical size of monetary policy shocks in VAR studies over our calibration sample. See, for example, Altig et al. (2011). Finally, we calibrate the financial shock to have the same persistence as the monetary policy shock, and a standard deviation such that the model meets the volatility targets specified at the beginning of this section.

3.8 Business-Cycle Statistics

In this section we show that the calibrated model matches the business-cycle facts well. In addition, we show that household heterogeneity changes the business cycle. In the HA model consumption is almost 15 percent more volatile than in the RA counterpart. At the same time investment is 10 percent less volatile. GDP on net is 4 percent more volatile in the HA model than in the RA counterpart.

Table 3 compares second moments implied by the model and the data (based on HP-filtered series with smoothing parameter 1,600). The data are described in Appendix D. The first three columns report second moments in the baseline model with heterogeneous agents (the HA model). The second block of three columns reports the second moments of the representative-agent version of the model (the RA model). These moments are included here for two reasons. First, because we use the RA model to calibrate the model to second moments in the data. Second, it shows how much the heterogeneity influences aggregate fluctuations. The final set of columns reports the moments in the data. The model fits the data well. The model also generates an increase in the skewness of earnings growth in recessions (not reported in the table). Namely, the average correlation of year-on-year GDP growth and the skewness of yearly earnings growth is 0.14. Still, the value falls short of the value of 0.5 reported for the same statistic in Guvenen et al. (2014).

A result of economic substance is that allowing for heterogeneity implies notable changes to the business cycle. The model with heterogeneous households generates much more volatility in aggregate consumption than we observe under representative households. It is important to bear in mind, however, that households in the model can save and that the supply of aggregate savings (capital and employment relationships) is endogenous to their desire to save. Therefore, the higher volatility of consumption does not translate one-to-one into more volatile aggregate demand. Rather, the volatility of output rises only by 4 percent. The reason is that the volatility of investment falls by 11 percent relative to the RA environment. Table 7 in the appendix shows that simple saver-spender models (introduced in more detail in Section 5.2) capture the change

Table 3: Model vs. Data – Second Moments

	Model						Data		
	HA: heterog. hh.			RA: represent. hh.			1984Q1-2008Q3		
	Std	Corr	AR(1)	Std	Corr	AR(1)	Std	Corr	AR(1)
Output and components									
GDP (GDP)	1.69	1.00	0.63	1.62	1.00	0.64	1.62	1.00	0.94
Consumption (c)	1.02	0.99	0.69	0.89	0.98	0.71	0.89	0.87	0.87
Investment (i)	5.28	0.98	0.73	5.86	0.99	0.71	5.09	0.96	0.89
Capacity utilization (v)	0.96	0.78	0.24	0.83	0.75	0.27	2.21	0.84	0.94
Labor market									
Employment $N(X)$	0.65	0.90	0.64	0.62	0.90	0.66	0.65	0.86	0.96
Unemployment $U(X)$	10.9	-0.90	0.65	10.2	-0.89	0.67	10.2	-0.86	0.95
Vacancies (V)	8.94	0.75	0.07	8.35	0.73	0.10	11.1	0.91	0.93
Job finding rate (f)	5.37	0.88	0.38	5.08	0.87	0.40	5.13	0.80	0.83
Productivity and Prices									
$GDP(X)/N(X)$	1.14	0.97	0.62	1.10	0.97	0.63	1.07	0.87	0.88
Wage $W(X)$	0.51	0.97	0.62	0.50	0.97	0.63	0.95	0.41	0.84
Inflation Π [1]	0.67	-0.32	0.62	0.67	-0.40	0.63	0.67	0.27	0.27
Nominal rate R [1]	0.97	-0.14	0.58	0.96	-0.25	0.60	1.24	0.61	0.92

Notes: The table compares moments of the data and two variants of the model (heterogeneous households, representative households). The model moments are based on 1,000 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 139 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 20 and last 20 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 data's. 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 ("AR(1)") shows the autocorrelation of the series. [1]: the nominal interest rate and inflation are reported in annualized percentage points.

in business-cycle dynamics only if calibrated to a large share of spenders.

The sections that follow have two purposes. First, in Section 4 will we contrast the transmission of shocks in the HA model and the RA variant, conditional on the baseline calibration of the Taylor rule $\phi_\pi = 1.5$, $\phi_u = 0.107$. This will illustrate, in particular, the reasons for the change in the business cycle stressed above. Thereafter, in Section 5, we will discuss the welfare implications both of monetary policy shocks and of the design of the monetary rule.

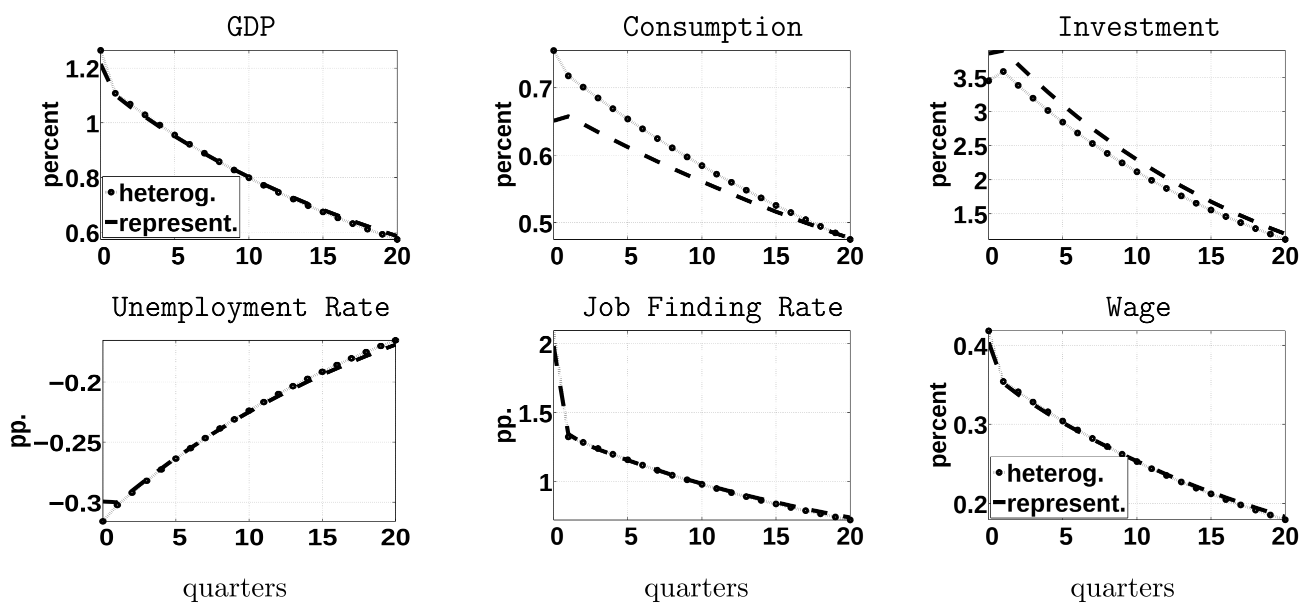
4 Transmission of TFP and Monetary Policy Shocks

Next, we discuss in detail how heterogeneity affects the transmission of shocks. The central result is: Allowing for household heterogeneity changes the transmission of shocks, in particular monetary policy shocks. For these, the consumption response on impact is about twice as large in the HA model as in the RA model. The impact response of GDP is larger as well, but less so than for consumption. We argue that this owes to the interaction of the precautionary savings motive with the endogeneity of aggregate investment in the HA model.

4.1 Transmission of a Technology Shock

We first discuss the response of the economy to a TFP shock. This shock is the main driver of the business cycle in the model. The starting point is the "stochastic steady state."[9] Figure 2 shows the effect of a one-standard-deviation positive TFP shock for the aggregate economy. The solid lines show the response in the baseline model (the model with heterogeneous households). The dashed lines show the response in the model with a representative household. Output

Figure 2: Response to a TFP Shock I



Notes: Impulse response to a one-standard-deviation TFP shock, Z. Solid line: the model economy with heterogeneous households. Dashed line: same economy but with a representative household. For most of the variables, the y axis shows percent deviations from the no-shock path (y-label "percent"). "pp." refers to the deviation from the no-shock path in percentage points. The x-axis shows time since the shock in quarters.

rises in response to the TFP shock in response to the TFP shock and the demand for labor services increases. Labor services firms, therefore, post more vacancies. The job-finding rate rises markedly, by about 2 percentage points on impact. The unemployment rate falls, namely,

[9] The stochastic steady state is defined as follows. We initialize the economy at the non-stochastic steady state. Then we simulate 500 periods of the stochastic economy, assuming that in each period unexpectedly the innovations to the three shocks are zero. The resulting state in period 500 is the "stochastic steady state."

by about 0.3 percentage point. The wage rises.[10]

What differs strongly is the composition of the increase in output. The HA model's consumption rises about 15 percent more, whereas its investment response is weaker than the RA model's. We turn to explaining these differences next.

Toward this end, Figure 15 in the appendix shows the steady-state savings policies for each type of household types. From this it is apparent that unemployed households generally dissave, at a rate that increases in wealth. Employed households are more complicated. Employed households of the patient type (β_H) have a positive target level of wealth, even if – for the low-skilled (s_1) – this may be just about one-tenth of annual income. Employed households that are impatient (β_L) will accumulate savings only if they are in one of the higher skill groups (s_3 and s_4). The TFP shock affects employment, unemployment risk, and income. On the one hand, it moves more households from unemployment to employment. For some households, the additional income will translate one-to-one into additional consumption, making consumption more volatile than in the RA model. This effect alone would be present in a simple saver-spender model of the business cycle as well. What is more, however, is that there are households who have some savings but risk hitting the borrowing constraint during an extended unemployment spell. The positive TFP shock leads these households to reduce their precautionary savings. They do so by selling shares and by influencing the investment policy of capital-services firms (as implicitly embedded in their influence on the stochastic discount factor), namely, in such a way that investment rises by less than in the RA model. Figure 3 shows the counterpart to this, the individual HA model household's consumption response on impact depending on the household's wealth, its time-preferences, skills, and employment status. For comparison, the horizontal dashed line shows the response in the RA model. The figure suggests that it is the unemployed, in particular, who adjust their consumption, as long as they hold wealth.[11] These households' future unemployment risk has fallen (since the job-finding rate rises persistently), rendering saving less important. In addition, the value of their shares has risen. This increases the scope for consuming out of wealth during any unemployment spell.

In sum, the consumption response alone would suggest that GDP in the HA model reacts very differently from the RA counterpart. The actual impact response of GDP differs only by four percent between the two variants, however. The key to understanding this is that part of

[10] The response of (un)employment is consistent with the responses to *permanent* TFP shocks identified by Ravn and Simonelli (2008) and Altig et al. (2011) by means of long-run restrictions, and the responses identified by sign restrictions to persistent but possibly transitory TFP shocks in Dedola and Neri (2007).

[11] Households without wealth cannot do so because, by assumption, unemployment benefits are constant over the business cycle and there is no borrowing.

Figure 3: Consumption Response to a TFP shock

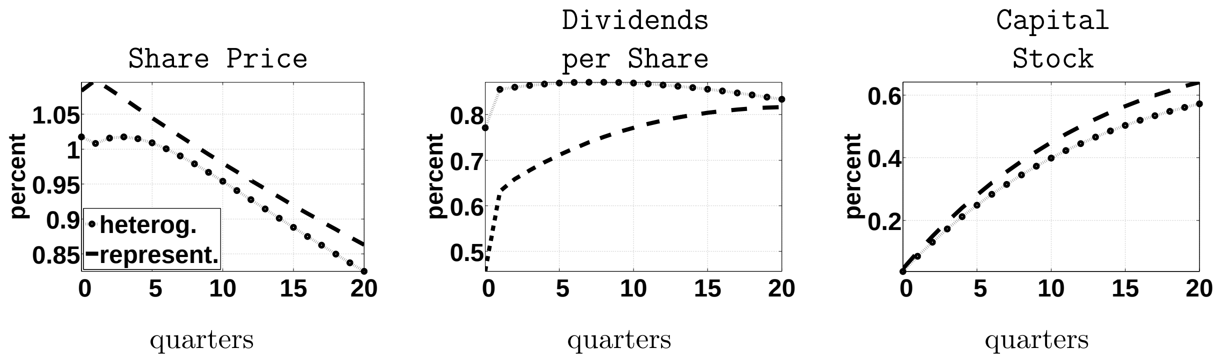
Notes: Consumption response (on impact) to a one-standard-deviation positive TFP shock by household type (β, e, a, s). For each decile of the wealth distribution, skills are ordered from lowest to highest ("s_1" to "s_4"). No bar means that, for that type, consumption on impact does not respond to the TFP shock. y-axis: percentage increase in consumption relative to no-shock baseline. For comparison, the dashed horizontal line reports the impact response in the RA model.

the mirror image of the stronger response of consumption to a TFP shock is that *investment* in the HA model does not rise by as much as in the RA counterpart. The compensating weaker response of investment shows the importance of modeling an economy in which *aggregate saving* can respond to shocks.

In the early quarters after the shock, the reduced demand for precautionary saving manifests itself in share prices that rise less in the HA economy than the RA counterpart. The initial response of the share price in the two economies differs by almost 10 percent; see the left panel of Figure 4. This is so even though the ex-ante real rate of interest (not shown) influenced by the central bank reacts rather similarly in the RA and HA model variant. Dividend payments are higher early on in the HA model reflecting the tendency not to reinvest income.

This section showed impulse responses taking the stochastic steady state as its point of

Figure 4: Response to a TFP Shock II



Notes: See Figure 2.

departure. Appendix E documents that there is considerable state dependence. For example, the same-size innovation to the TFP shock reduces both inflation and the unemployment rate by about twice as much if the shock happens in a deep recession rather than in a strong boom. This state dependence is already present in the RA model and allowing for household heterogeneity amplifies the dependence only slightly.

4.2 Transmission of a Monetary Policy Shock

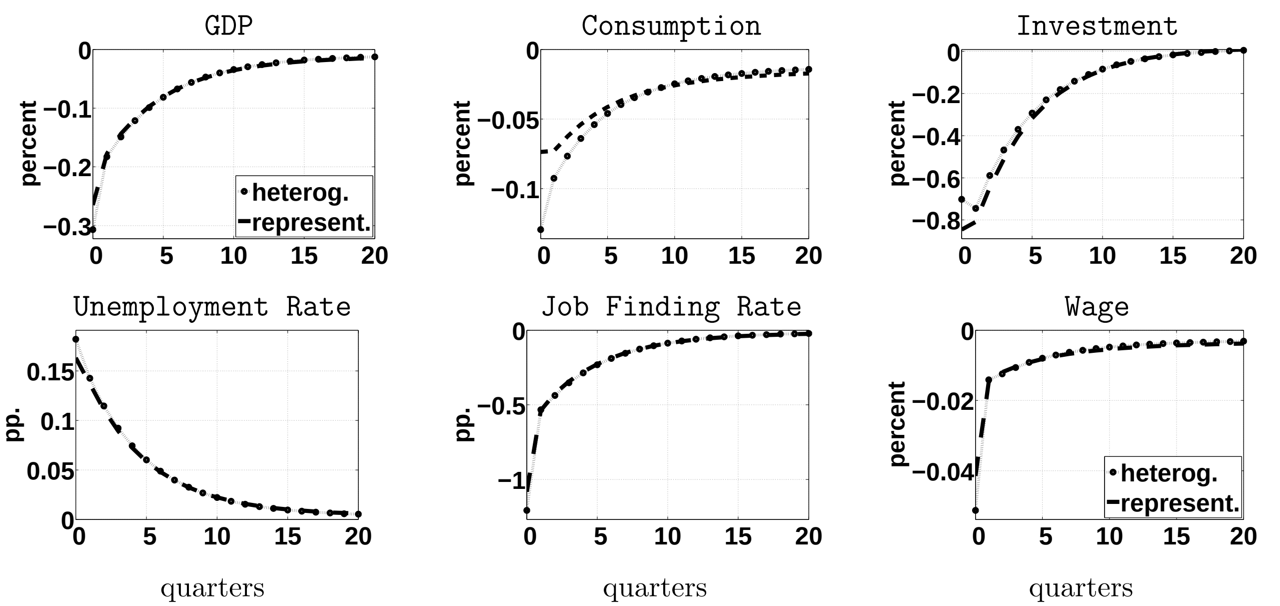
This section discusses the transmission of a contractionary one-standard-deviation monetary policy shock.[12] The mechanism through which contractionary monetary policy affects economic activity in our model is through an endogenous rise in markups. Such a rise in markups at a time when other sources of income fall suggests that monetary policy shocks could have sizable effects on inequality in an unequal society. The current section shows two important results. First, a contractionary monetary policy shock, indeed, increases inequality in wealth, income, and consumption, as is suggested by the empirical literature (for example, Coibion et al. 2012). Second, the section again stresses the importance of aggregate investment for the distributional effects. Namely, the rise in inequality is not as strong as would be suggested by the rise in markups alone. The key to this is the existence of physical capital and employment. Upon a monetary tightening the returns to these fall even more than wages do. Given that all households hold the same mix of shares (the mutual fund assumption) the portfolio mix dampens the distributional effects of monetary policy.

Figure 5 shows the response of the economy to a 25-basis-point (annualized) monetary tightening. That is, a one-standard-deviation monetary policy shock. By design, the monetary policy

[12] We omit a discussion of the effect of a financial shock on the aggregate economy and inequality. Apart from the response of the nominal rate, the financial shock – by construction – has very similar effects on the aggregate economy as a monetary policy shock.

shock is persistent. It therefore raises the long real rate of interest. Higher expected returns lead households to save more and cut back their spending for consumption by 0.13 percent (second panel in Figure 5). Since nominal prices are rigid, the ensuing fall in aggregate demand is met by an increase in intermediate goods firms' markups, validating the fall in activity. Firms invest less in light of the rising opportunity cost and falling demand. GDP overall falls by 0.3 percent. A monetary policy tightening strongly affects the labor market (second row): On the one hand,

Figure 5: Response to a Monetary Policy Shock I

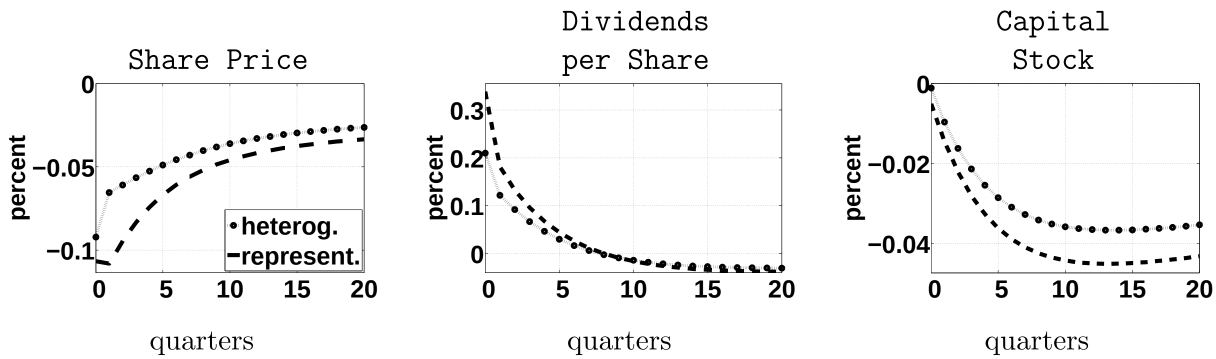


Notes: Impulse response to a one-standard-deviation monetary policy shock, D. For further details, see the notes to Figure 2.

the tightening reduces the demand for labor services and their price. On the other hand, the higher real rate of interest makes firms discount the future by more. This further exacerbates the fall in hiring. Along with vacancy posting, the job-finding rate falls markedly (by 1.2 percentage points). As employment falls, the unemployment rate rises by 0.18 percentage point (from a steady-state value of 6 percent to 6.18 percent). The reduced demand for production factors causes a reduction in capacity utilization and output per employed household. The wage falls.

In the HA model, the increase in unemployment and, thus, idiosyncratic risk tends to further exacerbate the fall in consumption (second panel, first row of Figure 5): Consumption on impact falls about twice as much as in the RA model. At the same time, through the mechanism discussed in Section 4.1, investment and the share price do not fall as much as in the RA counterpart (third panel, first row of Figure 5 and first panel Figure 6). The reason for this is the increased demand for precautionary savings. On net, output on impact falls by 20 percent more in the HA economy than the RA economy. Similarly, unemployment rises by more.

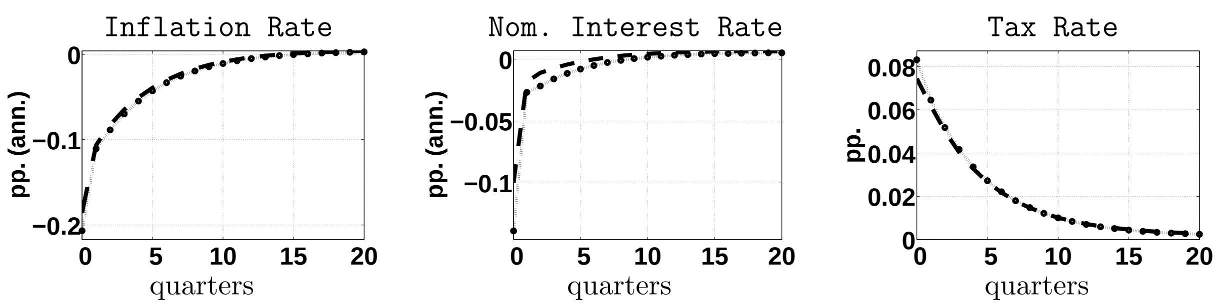
Figure 6: Response to a Monetary Policy Shock II



Notes: See Figure 5.

Lower aggregate demand means lower rental rates for both labor and capital services, and thereby lower marginal costs. Inflation falls by 0.2 percentage point (annualized), and somewhat more in the HA model than in the RA variant; see left panel in Figure 7. In other words, monetary policy shocks are more effective in the HA model.[13]

Figure 7: Response to a Monetary Policy Shock III

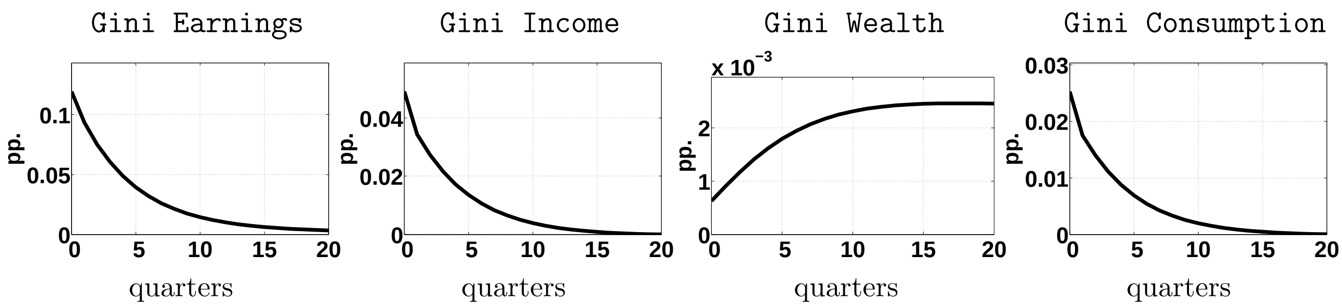


Notes: See Figure 5.

Turning to the effect of monetary policy shocks on inequality, Figure 8 shows the responses of the Gini indexes for earnings, income, wealth, and consumption to a monetary policy shock. What is notable here is that shocks that tighten monetary policy raise inequality in the economy. This is consistent with the empirical findings; for example, of Coibion et al. (2012). The effects

[13] In line with the stronger response of unemployment in the HA model and with the Taylor rule, equation (7), the HA model's central bank sets a lower real interest rate than in the RA counterpart. The above results have to interpreted in this light. Had the central bank engineered the same real rate path in the HA model as in the RA variant, the HA model would have shown a deeper recession still. Absent the endogenous stabilization inherent in the monetary rule, the gap in the GDP response between HA and RA model would have been larger than shown in the figures.

Figure 8: Response to a monetary policy shock: Gini Indexes



Notes: Impulse responses of Gini indexes of earnings (not conditioning on being employed), income, wealth, and consumption to a one-standard-deviation monetary policy shock, D. The figures show percentage point increases (an increase of "1" on the y-axis would increase the earnings Gini from, say, 0.64 to 0.65).

of a monetary policy shock on inequality are large compared to those of a TFP shock. The contractionary one-standard deviation monetary policy shock moves the Gini indexes by about as much as a *contractionary* one-standard deviation TFP shock (responses of the Gini indexes for TFP are not shown), even though GDP falls only about a fourth as much after the monetary policy shock.

5 Heterogeneous Welfare Effects

This section discusses the *welfare* consequences of monetary policy in an unequal society. Monetary policy is characterized both by its systematic response to the business cycle and monetary policy shocks. We study the welfare consequences of each of these in turn. In Section 5.1 we explore the welfare effects of one-time shocks using the baseline parametrization for the monetary rule. Our main finding is that the welfare costs of a contractionary monetary policy shock fall monotonically with a household's wealth. Still, there is no disagreement: None of the households in our economy benefit from contractionary monetary policy shocks. Thereafter, Section 5.2 explores the importance of the systematic response of monetary policy to unemployment. Our main finding is that with regard to the *systematic* response of monetary policy, there *is* strong disagreement. The (wealth-poorer) majority of the population favors a stronger response to unemployment than was embedded in the baseline. Such a response reduces their unemployment risk. The wealth-richer, instead, dislike such a response for it reduces the value of their wealth.

5.1 Welfare Effects of One-Time Shocks

Table 4 summarizes the welfare effects of one-time one standard deviation TFP and monetary policy shocks. The welfare gains (positive) or costs (negative) are measured as lifetime consumption equivalents. As a point of reference, we start with discussing the welfare effects of the

Table 4: Welfare Effects of One-Time Positive Shocks

		One-standard-deviation shock	
		TFP shock	Monetary shock
	RA, repres. agent	0.26	-0.01
	HA, household avg.	0.44	-0.07
By Wealth	Top 0.1 percent	0.47	-0.01
	Top 5 percent	0.41	-0.01
	80th–95th percentile	0.34	-0.01
	60th–80th	0.29	-0.02
	40th–60th	0.41	-0.06
	30th–40th	0.54	-0.10
	Bottom 30 percent	0.60	-0.12

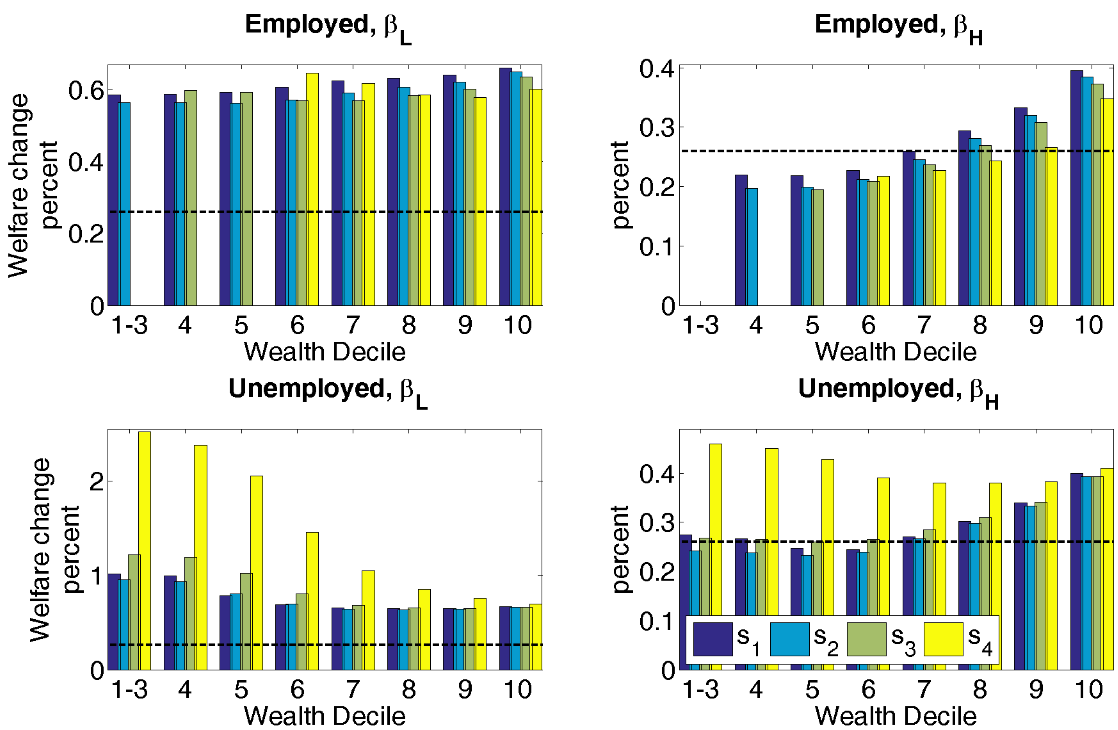
Notes: Lifetime consumption-equivalent welfare gains from a one-time one-standard-deviation positive TFP and positive monetary policy shock, respectively. Row "RA" reports consumption equivalents for a representative household. Row "HA" shows the average consumption equivalent in the population (using population weights).

expansionary TFP shock. The entry of "0.47" in row "Top 0.1 percent" and column "TFP" means that the 0.1 percent wealthiest households on average would be willing to permanently pay 0.47 percent of their consumption to experience a positive one-standard-deviation aggregate TFP shock today. The welfare gains are largest for the wealth-poorest 30 percent of the population, 0.60 percent. The average consumption equivalent across all households (row, "HA") is 0.44 percent. The wealth-poor tend to be more impatient or unemployed. They, thus, benefit most from the shock. The "upper middle class" (household around the 70th percentile) gain the least. On the one hand these households are far enough from their borrowing constraint. On the other, they rely mostly on labor income rather than financial income. The wage rigidity, however, imparts more of the TFP gains to capital owners than workers and, thus, to the wealthiest segment of the population.

Wealth, of course, is only one of the characteristics of a household. Figure 9 looks at the welfare gains from a TFP shock in more detail. Each of the four panels in that figure focuses on one specific combination of time preferences (β) and employment status. In each panel, the x-axis reports a household's wealth level by decile of the wealth distribution. For each wealth-decile, four bars (dark blue, light blue, green, yellow; from left to right) mark the skill of the household. No bar is shown if the mass of households with that combination is zero. The corresponding mass of the respective groups in the population is reported in Figure 14 in the appendix. The y-axis shows the consumption equivalents.

Next to the distributional effects of the TFP shock through the differences in income composition, the Figure shows clearly the effect that works through reduced unemployment risk. In particular, once conditioning on household discount factors (the β), the welfare gains from the TFP shock often are u-shaped in wealth: High-wealth households benefit disproportionately

Figure 9: Welfare Effects of an Expansionary TFP Shock by Type



Notes: Consumption-equivalent welfare gains (negative entries mean welfare losses) by household type (β, e, a, s). For each decile of the wealth distribution, skills are ordered from lowest to highest ("s_1" to "s_4"). No bar is shown for those types that do not have any mass in the population. The dashed horizontal line marks the welfare loss in the RA model.

from the increase in firm's profits. Low-wealth households, instead, benefit from the reduction in unemployment risk at a time when they are not well-insured against unemployment. Households with intermediate levels of wealth, instead, benefit to a lesser extent from the expansion: they are well-insured against unemployment risk to start with but have too few assets (relative to their labor income) to benefit from the expansion in profits. This u-shape is best visible in the bottom-right panel of Figure 9.

The welfare costs of a contractionary monetary policy shock, instead, are strictly decreasing in wealth, see the second column of Table 4). The wealth-poor on average are willing to pay as much as 0.12 percentage point of lifetime consumption to avoid a one-time contractionary one-standard deviation monetary policy shock, making their cost an order of magnitude larger than the wealthiest households'. It is also important to note that the same monetary policy shock would have had small welfare costs in the RA model (0.01 percent of lifetime consumption, see row "RA"). The main reason is that the shock seems rather "small" to start with: it raises the nominal interest rate temporarily 6.25 basis points above the level prescribed by the Taylor rule (0.25 percentage point when annualized). The small shock notwithstanding, in the HA model, the monetary policy shock has sizable welfare consequences.

Figure 10: Welfare Effects of a Contractionary Monetary Shock by Type

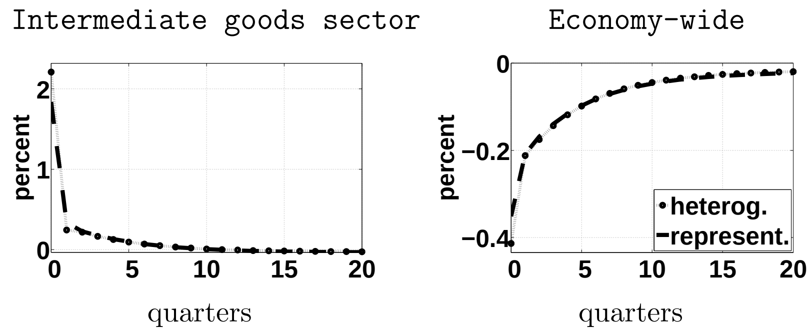
Notes: Consumption-equivalent welfare gains (negative entries mean welfare losses) by household type (β, e, a, s). For each decile of the wealth distribution, skills are ordered from lowest to highest ("s_1" to "s_4"). No bar is shown for those types that do not have any mass in the population. The dashed horizontal line marks the welfare loss in the RA model.

Figure 10 shows the welfare costs of a monetary policy shock by household type. Several observations are in order. Naturally, more impatient (low beta) households tend to be affected more negatively by a contractionary monetary policy shock than patient households. These households, in the model, also tend to be wealth-poor. Their higher preference for current consumption means that their welfare is hit particularly hard by a shock that reduces income today and which they will not smooth over time (since the market rate of return is lower than their rate of time preference). Even conditioning on a household's type, however, wealth remains negatively correlated with the costs of an unanticipated monetary tightening.

An important finding is that, all else equal, unemployed households are much more negatively affected by an unanticipated monetary tightening than employed households. Their welfare costs are three to four as large as those of employed households of otherwise the same characteristics. An unemployed low-beta, low-wealth household of high skills (s_3), for example, would be willing to forgo 0.45 percent of lifetime consumption to avoid what appears to be a rather small one-time monetary policy shock; see the green bar (the third bar from the left) for wealth decile 4 in the bottom-left panel of Figure 10. If the same household were employed, instead, it would lose only a third of this (first panel). A monetary policy shock tends to prolong the unemployment spell of an individual household. This means that lifetime earnings fall and the risk of exhausting savings rises. Last, and surprisingly perhaps, all else equal the higher a household's potential labor income is (the higher the skill level s) the more a household loses from a monetary contraction. For all households a monetary policy shock means that labor earnings fall and labor-earnings risk rises. What drives the welfare losses for the high-skilled is that a monetary policy shock causes them to lose income precisely when they are more productive than usual (the skill level s is persistent but stationary). For aggregate welfare, however, these households matter little (their mass being small, see Figure 14 in the appendix).

Figure 10 clearly shows that contractionary monetary policy shocks are less costly for wealthier households than for the wealth poor. All types of households agree, however, that they dislike the monetary policy shock. At first glance this lack of disagreement appears to contradict the evidence shown in the previous section. In particular, that section showed that dividends rise in response to a contractionary monetary policy shock (recall Figure 6) whereas labor income falls. The key to understanding why the distributional effects and the disagreement are not larger still is that a rise in dividends need not coincide with rising profits. This is so because the model has two quite different sources of *ex-post* profits that move in opposite direction after a monetary policy shock. One source of profits are the intermediate goods (sticky-price) firms. The left panel of Figure 11 shows that profits in the intermediate goods sector rise with tighter monetary policy. The reason is that a monetary contraction reduces marginal costs. Due to sticky prices, then, markups in the intermediate goods sector increase. This alone would suggest that wealthier households stand to benefit from contractionary monetary policy. For assessing the distributional effects of monetary policy shocks, it is central, however, to account for investment opportunities other than sticky-price firms. Namely, the above argument neglects the fact that capital and labor services firms can make profits and/or losses as well. Since both employment and capital are investment goods in our model, the losses that these types of firms incur after a monetary contraction can be steep. Indeed, both the rental rate of capital $r(X)$ and the rental rate for labor services $h(X)$ fall upon a monetary tightening (not shown in the figures). Taken

Figure 11: Response to a Monetary Shock – Profits



Notes: Response to a one-standard deviation contractionary monetary policy shock. Left panel: profits in the intermediate goods sector; right panel: profits in the overall economy (before investment and vacancy posting costs).

together, the profits of all three types of firms (labor, capital, intermediate goods) combined *fall* after a contractionary monetary policy shock, and more so than GDP; compare the right panel of Figure 11. Since all households with positive wealth hold assets through the mutual fund only, all of them bear the losses of capital goods firms and labor firms as much as the profits from intermediate goods producers. Monetary policy shocks do not merely redistribute wealth.

Whereas there is no disagreement with regard to the *unsystematic (shock) component* of monetary policy, we shall demonstrate next that there is considerable disagreement with regard to the *systematic response* of monetary policy to the business cycle.

5.2 Welfare Effects of a Transition to More Accommodative Monetary Policy

The systematic reaction of monetary policy to economic developments shapes the business cycle. Counter-cyclical monetary policy can stabilize unemployment. This helps insure households against having to run down their savings during a persistent unemployment spell. Not all of the households are exposed to that risk to the same extent, however. It is, therefore, natural to ask what type of *systematic* monetary policy different households would prefer. The question we ask in the current section is: "Would a certain household prefer to live in the baseline economy or have monetary policy change to being more or less responsive to unemployment?" Toward this end we look at a one-time unanticipated change in the interest-rate response to unemployment, ϕ_u, while keeping the response to inflation fixed at $\phi_\pi = 1.5$. We also keep the target levels for inflation and unemployment in the Taylor rule constant. The initial state is the stochastic steady state of the baseline calibration. Welfare is assessed taking transition effects into account.

The central finding of this section is that the dual mandate is alive and well: a large majority of households in the HA model are in favor of a monetary policy that stabilizes unemployment even if this means more volatile inflation. Wealth turns out to be an important determinant of a household's attitudes towards unemployment stabilization. Before discussing the results in detail, it will be useful to discuss the reasons for this. In the scenarios discussed here, a monetary policy that reacts more to unemployment stabilizes the unemployment rate at the expense of more volatile inflation. The unemployment rate is stabilized because the job-finding rate is. By stabilizing the job-finding rate the central bank removes part of the idiosyncratic risk that households face. This benefits, in particular, those households who rely primarily on labor income. The reduced labor-market risk tends to matter much less, however, for households that are asset-rich and, thus, well-insured. On the contrary, the unemployment stabilization hurts the wealth-rich. The reason is that reduced idiosyncratic risk means that households with positive target levels of wealth will reduce their precautionary savings. This in turn reduces the share price, and thus the value of the assets that the wealth-rich hold. There are two additional effects that explain the welfare gains and losses. The first is that in spite of the reduced capital stock (as savings fall), average employment rises,[14] which benefits Main Street in particular. The second is that as monetary policy stabilizes unemployment, inflation becomes more volatile. This increases the average price-adjustment costs. This reduces dividends, leading to a further fall in asset prices, further hurting Wall Street.

We turn to discussing the results in detail. The welfare effects of switching to more "dovish" or more "hawkish" monetary policy are presented in Table 5. The left-most column reports on more hawkish policy (a smaller response to unemployment), the four columns on the right on more dovish policy. In the RA model the optimal unemployment response would be $\phi_u = 0.46$ (the table shows results for $\phi_u = 0.5$, see the first row of the table). At this value, unemployment fluctuates about 41 percent less than in the baseline, while inflation volatility rises by 71 percent.[15] The second-to-last row of the table reports the share of households that would be in favor of abandoning the baseline policy rule for a rule with an alternative value of ϕ_u. In line with the results in the RA model, all households dislike switching to a more hawkish monetary policy ($\phi_u = 0.05$). The last four columns of the table ($\phi_u = 0.25$ through $\phi_u = 1.0$) show the welfare gains (compared to the baseline) from moving to more accommodative policy. Table 5 documents that a majority of households favor moving to more accommodative policy than prescribed by the RA model. In particular, 60 percent of households prefer $\phi_u = 0.75$ over $\phi_u = 0.5$ (64 percent

[14] The effect that in the search and matching model unemployment stabilization translates into lower unemployment on average has been documented by Hairault et al. (2010).

[15] The reason why full price stability is not optimal in the RA version is that the (Hosios, 1990) condition is violated in two ways: first, wages on average are too high from a social perspective (they remain in the bargaining set, however, and so are *privately* efficient) and, second, there is wage rigidity. Blanchard and Galí (2010) and Ravenna and Walsh (2012) show this result in smaller representative-agent economies.

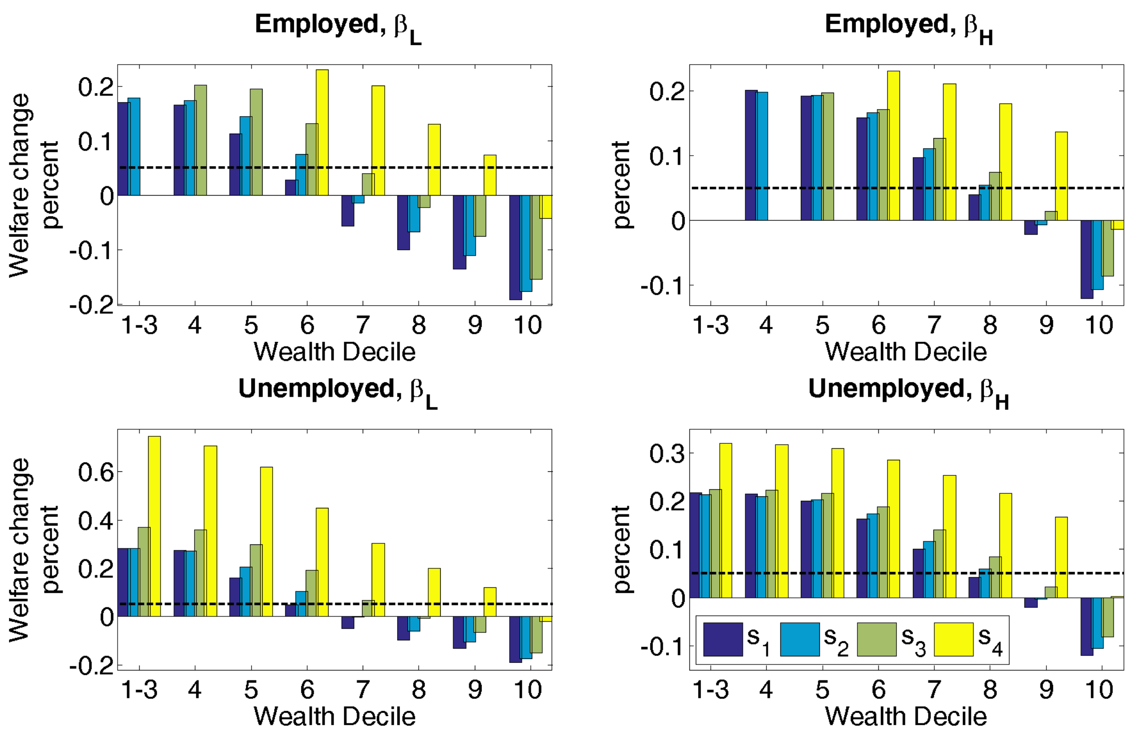
Table 5: Welfare Effect of Permanent Policy Change

		Response to unemployment, ϕ_u					
		0.05	baseline 0.107	0.25	0.5	0.75	1.0
	RA, repres. agent	-0.09	—	0.09	0.12	0.09	0.05
	HA, household avg.	-0.09	—	0.08	0.13	0.13	0.12
By Wealth	Top 0.1 percent	-0.14	—	0.07	0.02	-0.10	-0.23
By Wealth	Top 5 percent	-0.13	—	0.08	0.06	-0.03	-0.14
By Wealth	80th–95th percentile	-0.12	—	0.08	0.09	0.04	-0.02
By Wealth	60th–80th	-0.11	—	0.09	0.13	0.11	0.08
By Wealth	40th–60th	-0.09	—	0.09	0.16	0.18	0.18
By Wealth	30th–40th	-0.07	—	0.08	0.15	0.18	0.19
By Wealth	Bottom 30 percent	-0.07	—	0.07	0.14	0.17	0.18
	Percent in favor ...						
	... relative to baseline	0.0	—	99.7	99.7	94	84
	... relative to next-lower	—	100	99.7	92.5	60	48

Notes: Welfare effects of a permanent policy change from $\phi_u = 0.107$ to a different value. Lifetime consumption-equivalent welfare gains. Row "RA" reports consumption equivalents for a representative household. Row "HA" shows the average consumption equivalent in the population (using population weights). Rows "By Wealth" report the gains by wealth percentile. The final two rows show, respectively, the share of households in favor of abandoning the *baseline* for a policy with the value of ϕ_u shown in the respective column and the share in favor of having the respective ϕ_u response rather than the *next lower* value of ϕ_u shown in the table.

of the low-skilled, falling to 49 percent of the super-skilled). The table suggests that the median voter prefers a response to unemployment just below $\phi_u = 1$ (48 percent of households favor moving all the way to $\phi_u = 1$ instead of stopping at $\phi_u = 0.75$). With $\phi_u = 1$ unemployment is only about a third as volatile as in the baseline, whereas inflation is twice as volatile (not shown in the table). The move toward such accommodative policy favors the wealth-poor, whose welfare gain would amount to nearly 0.2 percent of lifetime consumption at the expense of the wealthy, who would *lose* a similar amount. At 0.41 percent of lifetime consumption, the welfare differences for the respective groups shown in Table 5 are large. There, thus, is substantial disagreement among households with regard to how accommodative systematic monetary policy should be. Indeed, the disagreement starts to show already at lower values of the response parameter. For example, almost all households (99.7 percent) are in favor of moving to $\phi_u = 0.25$ (second-to-last row in column $\phi_u = 0.25$). The few households that are not in favor are those that are both impatient and lower-skilled, but wealthy. Wealth-richer households that plan to dissave would be better off under more hawkish policy.[16]

Figure 12: Welfare Gains of Switching from Baseline to $\phi_u = 1$



Notes: This figure shows the welfare changes from a switch from the baseline monetary policy rule to one with $\phi_u = 1$ by the households' individual states. The dashed horizontal line shows the welfare gains from moving to that policy in the RA model. Otherwise, the notes to Figure 10 apply.

Figure 12 shows the welfare effects of a switch to $\phi_u = 1$ in greater detail. The structure of the figure is the same as that of Figure 10. What is apparent from the figure is that for each combination of skill, employment status, and patience, the welfare gains from more accommodative monetary policy monotonically fall in wealth. The figure also makes clear that a household's desire to (dis)save is an important determinant of the welfare losses of the wealthiest: whereas super-skilled rich households lose little from accommodative policy, it is the wealth rich with low earnings that lose most.[17]

[16] Employed higher-income households tend to save. As a result, income and wealth are correlated. Nevertheless, there remains substantial heterogeneity also within income groups. For example, 81 percent of super-skilled households prefer to move to $\phi_u = 0.5$ instead of $\phi_u = 0.25$ (results not shown in the table). For the low-skilled (s_1), the share is 93 percent. The households that would gain most from the more accommodative policy are those with low to median levels of wealth.

[17] Though somewhat outside of the current model, it may be useful to make an analogy that helps map the findings into the policy debate: the latter households are, to some extent, similar in characteristics to wealthy retirees: high wealth relative to labor income.

On a final note, it may be useful to compare the findings above with the optimal unemployment-response coefficients in a simpler saver-spender model, that we also computed (no table provided). For this model variant, we assumed that thirty percent of households are impatient (spenders, with time preferences given by β_L), based on the share of households with zero net worth in the data.[18] Spender households live on their own. The remaining households (savers with a discount factor of 0.99) are assumed to live in representative families that provide for full consumption insurance in the event of unemployment. The savers' welfare is maximized at a value of $\phi_u = 0.42$, close to what is optimal in RA model variant. Employed spenders prefer a value of $\phi_u = 1.21$, unemployed spenders would prefer a value above $\phi_u = 2$.[19] In sum, already the simpler saver-spender model would flag that there is substantial disagreement about what constitutes "good" monetary policy. It would fail to provide clear guidance, however, as to the policies favored by the middle-class and so as to the majorities in favor of the differing policies. The fact that most households in the HA economy have a positive target level of wealth (including impatient households with skills s_3 and s_4; cf. Figure 15) neither means that the median household would favor policies that are optimal for a "representative" saver household, nor does it mean that the median household favors policies aimed at spenders only.

6 Conclusions

Monetary policy affects both aggregate economic activity and the distribution of income risk. Toward assessing the distributional effects of conventional monetary policy, we have built a New Keynesian heterogeneous-agent DSGE model that features asset-market incompleteness, heterogeneity in preferences and skills, a frictional labor market, and sticky prices. The model was calibrated to the U.S. in tranquil times. Three main findings emerge.

First, we document that heterogeneity changes the monetary transmission mechanism and the business cycle. In the heterogeneous agent (HA) model, aggregate consumption is twice as responsive to a monetary policy shock as in a counterfactual representative-agent (RA) variant of the same model. At the same time, investment is smoother in the HA model. The reason is that monetary policy shocks affect earnings risk. In particular, households that face the risk of exhausting their savings in an unemployment spell will respond to a, say, contractionary monetary policy shock by reducing their consumption and increasing their precautionary savings.

[18] It is not entirely clear what the share of spenders should be in the calibration of the SP model. We also entertained a calibration with 50 percent of the households being spenders, in line with the mass of impatient households in the calibration of the HA model. The results were very similar to those reported below

[19] Only some of this is attributable to impatience. Even if spenders had the same time preferences as savers, the former would desire more unemployment stabilization, the preferred value being around $\phi_u = 0.9$ for employed and unemployed spenders.

As a result, in the aggregate, savings fall by less in the HA model than the RA counterpart. Since we allow for physical capital, an increase in the households' desire to save translates into a weaker fall in investment in response to a contractionary shock. On net, output volatility rises only by about 4 percent relative to the RA model variant.

Second, the average welfare consequences of monetary policy shocks are an order of magnitude larger with heterogeneous households. Contractionary monetary policy shocks lead to an increase in earnings, income, wealth, and consumption inequality. The welfare losses associated with such shocks strictly fall in wealth. Unemployed households tend to lose three to four times as much as employed households. And, conditioning on wealth, it is the households with the highest earnings capability when employed that lose most. Depending on time preferences, unemployed households with high earnings capability but no wealth would be willing to forfeit between more than 0.15 and a full percentage point of lifetime consumption to avoid the consequences of a monetary policy shock that temporarily raises the nominal interest rate by as little as 6.25 basis points (25 basis points annualized).

Third, and most importantly, our results suggest that the dual mandate should be kept alive and well: Main Street prefers monetary policy to deviate notably from price stability. The median-wealth household favors a response to unemployment that is about twice as strong as the optimal response in the RA model. At this policy inflation is twice as volatile as in our baseline calibration, while unemployment is only a third as volatile as in the baseline. The wealth-poorer households like such a policy because it reduces earnings risk. They reduce their precautionary savings in response. The ensuing fall in the price of assets also explains why the wealth-rich dislike such dovish policy. Indeed, for Wall Street (the wealthiest households) implementing this dovish policy instead of their preferred policy can mean a welfare loss equivalent to 0.3 percent of lifetime consumption.

To the best of our knowledge our framework is the first that provides a global solution to a New Keynesian model with search and matching frictions, physical capital, and rich household heterogeneity. Several avenues suggest themselves for future work. First, social insurance itself is one of the drivers of wealth inequality, compare Hubbard et al. (1995). Exploring how labor-market policies and monetary policy interact in an unequal society is an important avenue for future research. Second, the paper has abstracted from labor-market heterogeneity in unemployment risk and wage risk. At the same time, we replicate only about a quarter to a third of the correlation of skewness in earnings and the business cycle documented by Guvenen et al. (2014). Extending the framework to get closer to their facts would further increase the link between labor-income risk and the business cycle and, most likely, the role for stabilization policy.

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—— Appendix – For Online Publication ——

A The Mutual Fund's Discount Factor

This appendix gives the exact formula for the mutual fund's discount factor. Notice that in equilibrium knowledge of X and X' implies knowledge of $\widetilde{X}'$. The stochastic discount factor is defined as follows:

$$\begin{aligned}
&Q(X, X') = \\
&\quad \textstyle\int_{\{1\}\times S\times B\times A} \sum_{\beta'\in B} \pi_B(\beta, \beta') \sum_{s'\in S} \pi_S(s, s')\, \beta \left(g_a(X, 1, s, \beta, a) \frac{\left(1-\lambda+\lambda f(\widetilde{X}')\right) u_c(g_c(X', 1, s', \beta', g_a(X, 1, s, \beta, a)))}{u_c(g_c(X, 1, s, \beta, a))} \right) d\mu(e, s, \beta, a) \\
&+ \textstyle\int_{\{1\}\times S\times B\times A} \sum_{\beta'\in B} \pi_B(\beta, \beta') \sum_{s'\in S} \pi_S(s, s')\, \beta \left(g_a(X, 1, s, \beta, a) \frac{\left(\lambda(1-f(\widetilde{X}'))\right) u_c(g_c(X', 0, s', \beta', g_a(X, 1, s, \beta, a)))}{u_c(g_c(X, 1, s, \beta, a))} \right) d\mu(e, s, \beta, a) \\
&+ \textstyle\int_{\{0\}\times S\times B\times A} \sum_{\beta'\in B} \pi_B(\beta, \beta') \sum_{s'\in S} \pi_S(s, s')\, \beta \left(g_a(X, 0, s, \beta, a) \frac{\left(f(\widetilde{X}')\right) u_c(g_c(X', 1, s', \beta', g_a(X, 0, s, \beta, a)))}{u_c(g_c(X, 0, s, \beta, a))} \right) d\mu(e, s, \beta, a) \\
&+ \textstyle\int_{\{0\}\times S\times B\times A} \sum_{\beta'\in B} \pi_B(\beta, \beta') \sum_{s'\in S} \pi_S(s, s')\, \beta \left(g_a(X, 0, s, \beta, a) \frac{\left((1-f(\widetilde{X}'))\right) u_c(g_c(X', 0, s', \beta', g_a(X, 0, s, a)))}{u_c(g_c(X, 0, s, a))} \right) d\mu(e, s, \beta, a),
\end{aligned} \tag{10}$$

Above, $u_c(c)$ marks the marginal utility of consumption.

B Definition: Recursive Equilibrium

Definition 1 (Recursive equilibrium) *A recursive equilibrium is a set of functions* $G(X)$, $\widetilde{G}(X)$, $\hat{G}(\widetilde{X})$, $W(X, e, s, \beta, a)$, $g_a(X, e, s, \beta, a)$, $g_c(X, e, s, \beta, a)$, $f(\widetilde{X})$, $p_a(X)$, $d_a(X)$, $w(X)$, $\tau(X)$, $h(X)$, $Q(X, X')$, $J_L(X, s)$, $V(\widetilde{X})$, $r(X)$, $J_K(X, k)$, $i(X)$, $v(X)$, $K'(X)$, $P(X)$, $y_j(X, P_j)$, $J_I(X, P_{j,-1})$, $k_j(X)$, $\ell_j(X)$, $P_j(X)$, $\Pi_j(X)$, $y(X)$, $R(X)$ *such that:*

1. *Given* $\widetilde{G}(X)$, $f(\widetilde{X})$, $w(X)$, $p_a(X)$, $d_a(X)$, $G(X)$, *and* $\tau(X)$, *value function* $W(X, e, s, \beta, a)$ *is a solution to the household's problem.* $g_a(X, e, s, \beta, a)$ *and* $g_c(X, e, s, \beta, a)$ *are the associated optimal decision rules.*

2. *Given* $h(X)$, $w(X)$, $Q(X, X')$, *and* $G(X)$, $J_L(X, s)$ *solves the problem of a labor agency.* $V(\widetilde{X})$ *satisfies the free-entry condition in the labor agency sector.* $f(\widetilde{X})$ *is consistent with* $V(\widetilde{X})$.

3. *Given* $r(X)$, $Q(X, X')$, *and* $G(X)$, $J_K(X, k)$ *solves the problem of a capital-producing firm.* $i(X)$, $v(X)$, *and* $K'(X)$ *are the associated optimal decision rules.*

4. *Given* $r(X)$, $v(X)$, $h(X)$, $P(X)$, $y_j(X, P_j)$, *and* $Q(X, X')$, *value function* $J_I(X, P_{j,-1})$ *solves the problem of an intermediate good producer.* $k_j(X)$, $\ell_j(X)$, $P_j(X)$, *and* $\Pi_j(X)$ *are the associated optimal decision rules.*

5. *Given $P(X)$ and P_j, $y_j(X, P_j)$ and $y(X)$ are the optimal decisions of final good producers.*

6. *The aggregate discount factor $Q(X', X)$ satisfies equation (10).*

7. *$d_a(X)$ satisfies the flow budget constraint of mutual funds (9).*

8. *The wage per efficiency unit of labor is given exogenously by $w(X)$ (5).*

9. *The labor tax $\tau(X)$ satisfies the government budget constraint (8).*

10. *The nominal interest rate $R(X)$ satisfies the Taylor rule (7).*

11. *The aggregate laws of motion $G(X)$, $\widetilde{G}(X)$, and $\hat{G}(\widetilde{X})$ are consistent with the relevant optimal decision rules.*

12. *All market clearing conditions are satisfied.*

C Solution Algorithm

This appendix outlines the solution method of an equilibrium with aggregate uncertainty. The method is a version of the method developed by Krusell and Smith (1998) and is closely related to the solution method based on reference distributions described in Reiter (2002) and Reiter (2010).[20]

1. Following Reiter (2010) we approximate the aggregate state of the economy by $X = (K, N, Z, \zeta_F, \zeta_R)$ and assume that there is a distribution selection function $\hat{\mu}$, a mapping from X into the space of all distributions on the household state variables. We approximate such a distribution following Young (2010) as a histogram on the product of skill state, the discount factor, employment state and a grid on the wealth distribution. All agents use this function to construct their forecasts about the evolution of the economy. We discretize X and interpolate between points using a Smolyak approximation (see Krueger and Kubler 2004).

2. Solve the model without aggregates shocks and follow the steps in Reiter (2010) to construct a first guess for the distribution selection function $\hat{\mu}$.

[20] 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. The current method allows for a faster solution of the model, but results were close to each other when we compared both methods.

3. Form an initial guess for the following: the price of the asset, $P_a(X)$, and the terms $\mathbb{E}Q(X,X')\phi_P\Pi(X')(\Pi(X')-\overline{\Pi})$, $\mathbb{E}Q(X,X')\frac{1}{\Pi(X')}$, $\mathbb{E}Q(X,X')\left[r'(X')v' + \frac{1}{\zeta'(i'/K')}\left(1-\delta(v')+\zeta\left(\frac{i'}{K'}\right)\right) - \frac{i'}{K'}\right]$, and $\mathbb{E}\big[Q(X,X')(1-\lambda)J_L(X',s')\big]$ each as functions of X. For a shorthand, we denote these guesses by $\Sigma(X)$.[21]

4. Given these initial guesses, perform the following steps

   (a) Given $\Sigma(X)$ use a numerical equation solver to obtain the solution to the firms' and government's equations on the grid.

   (b) Interpolate the static choices.

   (c) Given the solutions obtained in the previous step, iterate on the value function of the households.

      i. Set a guess for the value function $W(X,e,s,\beta,a)$.

      ii. Use the Bellman equation to update the value function.

      iii. If the updated value function is close to the guess, this step is done. The optimal decision rules $a' = g_a(X,e,s,\beta,a)$ and $c = g_c(X,e,s,\beta,a)$ are obtained. Otherwise, go back with an updated value function.

   (d) Use $\hat{\mu}$ and the solutions to the firms' and government's problems along with the optimal decision rules to compute the discount factor (10) on the grid. Use this to update $\Sigma(X)$ to $\Sigma'(X)$. $P_a(X)$ is updated by solving for the market-clearing price at each grid point using the reference distribution. If $\Sigma(X)$ and $\Sigma'(X)$ are close, go to the next step, otherwise use a weighted average of $\Sigma(X)$ and $\Sigma'(X)$ and start with the firms' and government's equations again.

   (e) Simulate the model. Notice that, for each period a market-clearing p_a has to be found, in the same manner as in Krusell and Smith (1997).

      i. Set the initial state and the initial type distribution. Use the steady-state values as the initial guess.

      ii. At the beginning of period t, draw a new set of shocks. We have the aggregate state in period t, (K_t, N_t, Z_t, D_t).

      iii. Set a guess for the share price $\hat{p}_a$, using the forecasting function with $P_a(X)$.

[21] For the initial guess, we solved the representative-agent version of our model (setting $\beta = 0.99$ so as to match the same real rate). Alternatively, we could have started with the choices in the heterogeneous-agent model in the steady state and guessed $Q(X,X') = 0.99$.

iv. Conditional on $\hat{p}_a$, and the aggregate state variables in period t, solve the problem of the households.

v. Check market clearing. Compute the excess demand for the shares. If it is zero, a market-clearing price in period t, $p_{a,t}$, is obtained for period t. K_{t+1} and N_{t+1} can be computed. Go to the next step. Otherwise, update $\hat{p}_a$ and go back to the previous step.

vi. Update the type distribution and aggregate state variables using $p_{a,t}$ and go to period $t+1$.

vii. Keep simulating until period $T = T_0 + T_1 = 500 + 3000$ periods.

(f) The previous step generates a time series of household distributions $\{\mu\}_{t=0}^{T}$. Drop the first T_0 periods. Using the time series for $t = T_0 + 1, ..., T$ construct a new reference distribution function $\hat{\mu}'$ following Reiter (2002).

(g) Compare $\hat{\mu}$ and $\hat{\mu}'$. If they are close, an equilibrium is obtained. Stop. Otherwise, update $\hat{\mu}$ and return to the firms' and government's problem.

In practice, as ζ_R and ζ_F have the same persistence under our calibration, the only variable affected differently by the two shocks is the nominal interest rate. Therefore, it is possible to solve the model while merging them into one state variable. During simulations of the model we distinguish between the two shocks in order to capture the right movements in the nominal interest rate given our calibration.

D Data and Details on the Calibration

This appendix provides further details on the data used and the calibration.

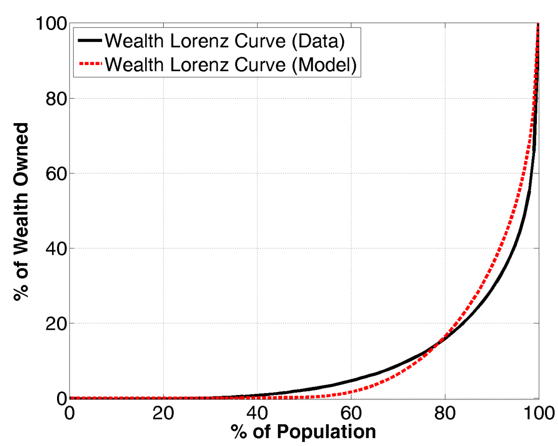
D.1 Data in Table 3 of the Main Text

The data we compare the model to in Table 3 are either quarterly already or are quarterly averages of monthly data. They are seasonally adjusted, if necessary. Unless noted otherwise, their source is the St. Louis Fed's FRED II database. We start with series that cover the period 1979Q1 to 2013Q3. After filtering them, we drop the first and last 20 quarters to arrive at a sample covering the period 1984Q1 to 2008Q3. Nominal variables are deflated by the GDP deflator, which we also use as our measure of inflation, Π. Personal consumption expenditures, c include total durable and non-durable consumption expenditures as well as services. Investment, i, is gross private domestic investment. Our measure of GDP is the sum of consumption and investment. Capacity utilization, v, is measured by the quarterly average of the Board of Governors' headline index of industrial capacity utilization. We use the civilian unemployment rate, $U(X)$, among those 16 years of age and older. Employment, $N(X)$, is one minus this measure. We measure vacancies V using Barnichon's (2010) composite help-wanted index. The data counterpart to the job-finding rate, f, is the quarterly average of the monthly transition probability from unemployment to employment in the Current Population Survey (CPS). The data are adjusted for time aggregation as in Shimer (2012). The wage, $W(X)$ is computed as wage and salary accruals from the national accounts divided by the GDP deflator. The interest rate, R, is the quarterly average of the effective federal funds rate.

D.2 Details on the Calibration

Figure 13 shows the wealth Lorenz curve for U.S. households aged 21-65 as a red dashed line. The data are from the 2004 Survey of Consumer Finances. For the construction of the wealth variable, we follow Díaz-Giménez et al. (2011). A solid line shows the model's nonstochastic steady-state counterpart.

Figure 13: Wealth Lorenz Curve



E State Dependence of Impulse Responses

This appendix documents the state dependence of the impulse responses and the extent to which heterogeneity amplifies the state dependence.

E.1 TFP Shocks: State Dependence

Figure 16 analyzes the extent to which a TFP shock has different effects depending on the state of the business cycle. We consider three such states: a deep recession (dashed line), a boom

Table 6: "Wall Street's" and "Main Street's" Income Sources

Wealth percentile	0-5	5-20	20-40	40-60	60-80	80-95	95-100
Data: 2004							
Labor income	92	83	91	89	89	81	55
Financial income	1	1	2	5	6	14	41
Transfers	7	16	8	6	5	6	3
Model (steady-state)							
Labor income	96	96	97	97	81	57	32
Financial income	0	0	0.1	2	18	42	68
Transfers	4	4	3	1	1	1	0.3

Notes: Share of income coming from labor and financial income, respectively, by percentile of the wealth distribution. The data are from the Survey of Consumer Finances (2004), for households aged 21-65. "Financial income" includes the categories financial income, business income, and capital gains/loss. Labor income does not include social security or pensions.

Table 7: Second Moments – Comparison HA, RA, and Saver-Spender Variants

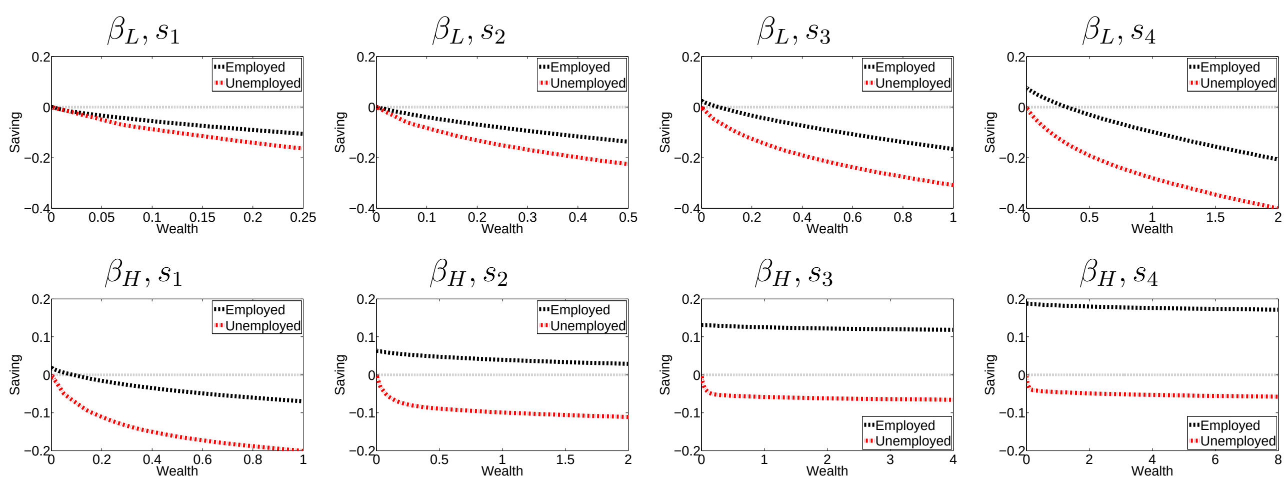
	heterog. hh. (HA)			represent. hh. (RA)			Saver-Spender SP30			SP50		
	Std	Corr	AR(1)	Std	Corr	AR(1)	Std	Corr	AR(1)	Std	Corr	AR(1)
GDP (GDP)	1.69	1.00	0.63	1.62	1.00	0.64	1.66	1.00	0.63	1.68	1.00	0.63
Consumption (c)	1.02	0.99	0.69	0.89	0.98	0.71	0.94	0.98	0.70	0.98	0.99	0.68
Investment (i)	5.28	0.98	0.73	5.86	0.99	0.71	5.66	0.99	0.72	5.51	0.98	0.72
Capacity utilization (v)	0.96	0.78	0.24	0.83	0.75	0.27	0.89	0.75	0.25	0.95	0.76	0.24
Employment $N(X)$	0.65	0.90	0.64	0.62	0.90	0.66	0.64	0.90	0.65	0.66	0.90	0.65
Unemployment $U(X)$	10.9	-0.90	0.65	10.2	-0.89	0.67	10.7	-0.90	0.66	10.9	-0.90	0.65
Vacancies (V)	8.94	0.75	0.07	8.35	0.73	0.10	8.68	0.73	0.08	8.97	0.73	0.07
Job finding rate (f)	5.37	0.88	0.38	5.08	0.87	0.40	5.26	0.87	0.39	5.42	0.87	0.37
$GDP(X)/N(X)$	1.14	0.97	0.62	1.10	0.97	0.63	1.11	0.97	0.63	1.12	0.97	0.62
Wage $W(X)$	0.51	0.97	0.62	0.50	0.97	0.63	0.50	0.97	0.63	0.51	0.97	0.62
Inflation Π [1]	0.67	-0.32	0.62	0.67	-0.40	0.63	0.68	-0.35	0.62	0.69	-0.31	0.61
Nominal rate R [1]	0.97	-0.14	0.58	0.96	-0.25	0.60	0.98	-0.19	0.59	1.00	-0.14	0.58

Notes: Same as Table 3, but listing the saver-spender model variants with 30 percent ("SP30") and 50 percent ("SP50") of spenders instead of the data.

(dotted line), and the stochastic steady state (circles). The deep recession state is obtained as follows. Starting at the stochastic steady state, we feed a sequence of five periods of negative one-standard-deviation TFP shocks, and one-standard-deviation contractionary monetary and financial shocks into the model. The state of the economy after that sequence of shocks is the "deep recession state." The boom state is the result of the same sequence of shocks but with the opposite sign. The first row shows the response of the model economy with a representative

Figure 14: Mass of Households by Idiosyncratic State

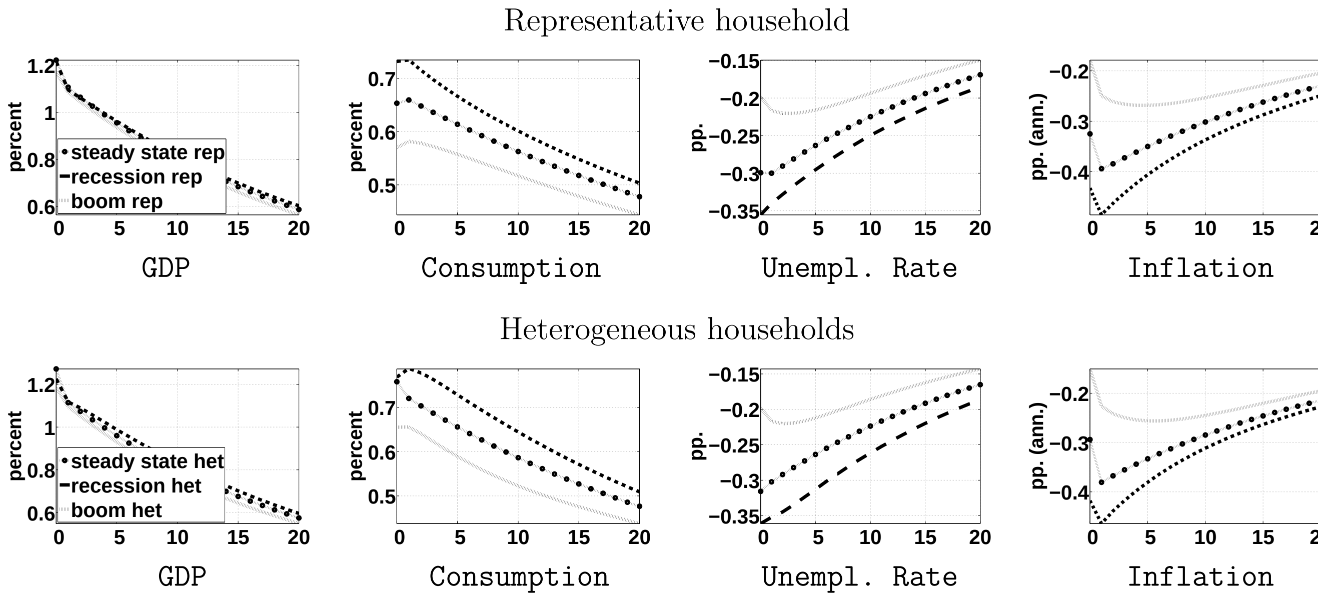
Figure 15: Savings Policy Functions



Notes: Savings policy as a function of current wealth. Policy functions evaluated in the stochastic steady state. x-axis: wealth as a share of annual potential labor income, Wealth:= $p_a \cdot a/(4 \cdot s \cdot w)$, where $s \in S$. y-axis: saving as a share of annual potential labor income, Saving:= $p_a \cdot (a' - a)/(4 \cdot s \cdot w)$. Positive values thus mean accumulation of wealth. Negative values mean dissaving.

agent, the second row the economy with heterogeneous households. We start by discussing the representative-agent economy. A sequence of expansionary shocks means that the unemployment

Figure 16: Effect of State of the Economy on IRFs to TFP Shock



Notes: Impulse response to a 1 standard deviation TFP shock, Z. First row: model economy with representative households. Second row: model economy with heterogenous households. In each of the panels, the response indicated by circles is the response starting from the steady state (as in figure 2) and the response indicated by dashes starts from a deep recession state. The dotted line marks responses starting in a boom. Whenever the figure shows percent responses, it normalizes the response by the steady-state value of the respective variable. This means that larger percent responses also mean larger responses in levels.

rate is lower than in the non-stochastic steady state. This makes hiring more costly for labor-services firms. The costs for labor services increase. As a result, an expansion in TFP has only half the impact on the unemployment rate in a boom as in a recession. Similarly, inflation falls only half as much in a boom as in a recession. Relatively higher costs for labor services mean that, in order to take advantage of the TFP shock, the mutual funds increasingly invest more in physical capital in a boom than they would in a recession (not shown). As a result, consumption responds by less (relative to consumption in the non-stochastic steady state) in the boom than in the recession. Again, the response of output is affected to a lesser extent.

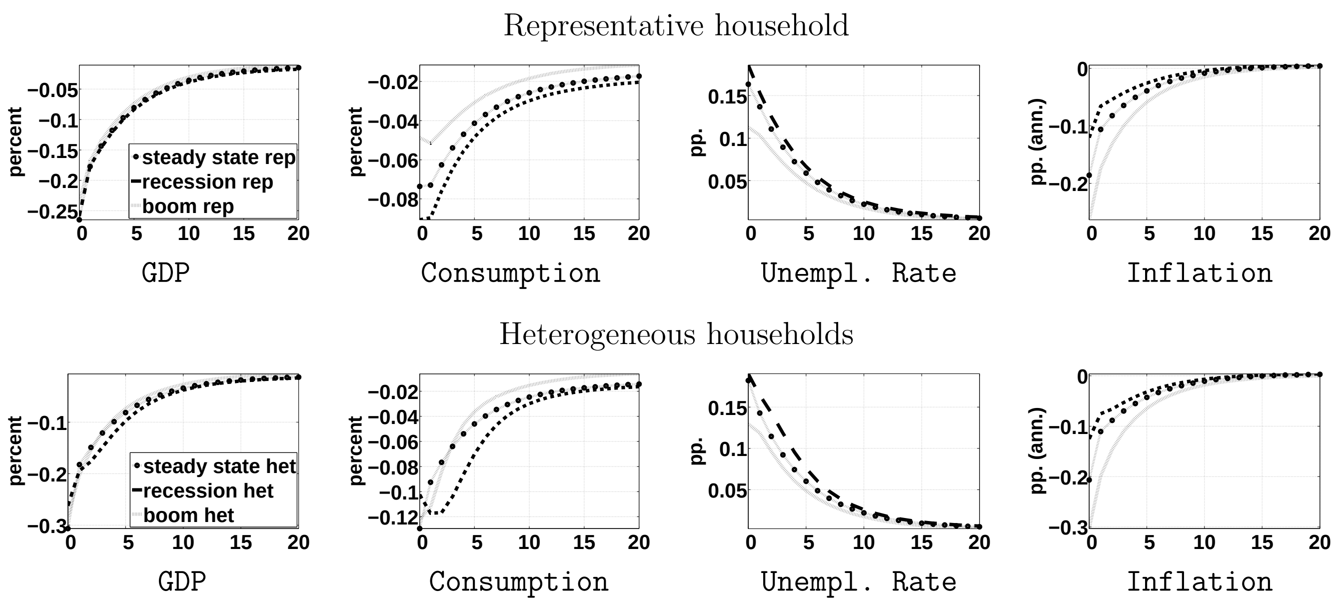
The model economy with heterogeneous households inherits the state-contingence of the responses from the representative-agent economy. What is interesting, however, is that the heterogeneous-agent economy alters the response of consumption in deep recessions. First, relative to the steady state, consumption responds by less on impact in the heterogeneous-agent economy because more households find themselves close to the borrowing constraint in the recession. As a result, they take advantage of the rising incomes that emerge from the expansionary TFP shocks by consuming but also rebuilding their savings. Consumption in a deep recession, therefore, only gradually builds up in response to an expansionary TFP shock.

In sum, in both the RA and HA economies there is notable state dependence of the responses. Responses of consumption, unemployment and inflation to a TFP shock are much larger in a recession than in a boom. The difference between the HA and RA models' responses is state-dependent as well.

E.2 Monetary Policy Shocks: State Dependence

Figure 17 analyzes the extent to which the impulse responses to a contractionary monetary policy shock are state-dependent. Similar to the results we obtained for the TFP shock, the impact of a monetary policy shock is state-dependent, and considerably so. In the heterogeneous-agent economy, the response of GDP to a contractionary monetary policy shock is 20 percent larger (GDP falls by 0.05 percentage points more) in a boom than in a recession. The representative-agent economy shows less (if any) of such state dependence in the response of GDP. Both the RA and HA models have considerable state-dependence in the inflation response, however. Inflation falls almost three times as much in response to a monetary policy shock if that shock hits in a boom than if it hits in a recession. This is so even though the response of the unemployment rate is almost 50 percent larger in a deep recession than in a steep boom. Putting this in slightly different terms, the responses shown here suggest that the "sacrifice ratio" (measured as the rise in unemployment for a given fall in inflation) is considerably lower in boom times than in recessions. Or, putting it still differently, monetary policy (through an expansionary monetary policy shock) can more easily increase output without having to jeopardize price stability in recessions than in booms. Heterogeneity further increases the scope for state-dependent responses to monetary policy shocks. This is most clearly visible again for the consumption response: in a recession, more households will be close to the borrowing constraint or, more generally, farther below their target level of wealth. As a result, those households are less susceptible to the intertemporal substitution that a monetary tightening causes. Actually, on impact, in the HA model consumption falls by less in a recession than in a boom (or in the steady state). Over time, however, in the HA economy, the consumption response is considerably stronger and much more persistent in a recession than in a boom.

Figure 17: Effect of State of the Economy on IRFs to a Monetary Policy Shock



Notes: Impulse response to a one standard deviation monetary policy shock, D. First row: model economy with representative households. Second row: model economy with heterogeneous households. In each of the panels, the response indicated by circles is the response starting from the steady state (as in figure 5) and the response indicated by dashes starts from a deep recession state. The dotted line marks responses starting in a boom. Whenever the figure shows percent responses, it normalizes the response by the steady-state value of the respective variable. This means that larger percent responses also mean larger responses in levels.