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

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Abstract

This paper investigates the distributional consequences of monetary policy in a New Keynesian business cycle model, with the novel feature of rich household heterogeneity. Households differ in the amount of savings, labor productivity, and employment status. Labor-market transitions are subject to matching frictions. Conditional on the state of the business cycle, we find strong distributional effects of monetary policy as well as feedback from heterogeneity to the transmission of policy. We provide examples in which systematic monetary policy has notable distributional implications through an effect on average employment.

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1 Introduction

Monetary policy, not unlike taxes or government expenditures, affects both aggregate economic activity and the distribution and riskiness of income. The latter is important since, in the data, households' sources of income differ starkly. Wealthier households receive financial and business income, whereas other households rely primarily on labor income or transfers. To be precise, the bottom 80 percent of the wealth distribution, "Main Street," receive virtually none of their income from financial assets, whereas "Wall-Street", the 5 percent wealth-richest households, receive 40 percent of their income from financial assets.[1]

The current paper assesses the implications of these differences in income composition for monetary policy. Toward this end, we build a dynamic stochastic general equilibrium (DSGE) model that features asset-market incompleteness and labor-market frictions. The model is designed to capture the concentration of wealth in the U.S. economy. Apart from adding heterogeneity, our model deliberately stays close to the New Keynesian model, which has become the workhorse model to analyze monetary policy. We ask if heterogeneity matters for monetary transmission, if monetary policy has notable distributional effects in the short-run, and what the distributional impacts of different monetary policies are in the long-run. We then ask if the majority of households would prefer systematically more accommodative monetary policy, and under which circumstances.

For the remainder of this paper, monetary policy is represented by a simple rule for the nominal interest rate. Unanticipated monetary policy shocks apart, the central bank sets the nominal interest rate in response to deviations of inflation from a target value and deviations of unemployment from its long-run level. Throughout most of the paper, the inflation target will be taken to be two percent per year. Clearly, this is a simplistic description of monetary policy. For the purpose of the current paper, this is useful, however. On the one hand, it makes clear that the results are not driven by a fundamental failure of monetary policy. On the other hand, it helps illustrate that even small differences in the parameters that govern the rule have substantial distributional consequences.

As to our findings, we find that both the systematic and unsystematic components of monetary policy have notable distributional consequences. In terms of life-time consumption equivalents, households without asset wealth lose twice as much from a contractionary monetary shock as those who do hold wealth. The principal reason for this heterogeneity is the endogenous

[1] These figures are from the 2004 Survey of Consumer Finances. See Table 18 in Appendix D details on sample selection.

evolution of different sources of incomes. Wealth-poor households rely almost exclusively on labor income. Labor income falls when a higher policy rate induces higher unemployment. At the same time, markups in the model are endogenous. The induced recession leads to higher markups, which cushions the income of the wealth-rich. The unemployed will seek to smooth consumption. It is the rich saver who benefits from the resulting fall in asset prices by being able to accumulate wealth more cheaply. We share this channel with Glover et al. (2011). The effects are very persistent and continue to be present even once the monetary impulse on the aggregate economy has largely died out. There is also important stratification by income levels and employment. A median-wealth household that is unemployed but would be highly productive in the market-place would be bound to lose an order of magnitude more from the contractionary monetary shock than the average household. The reason is that contractionary monetary policy reduces the job-finding rate persistently. Since individual productivity in the model is risky, this means that a potentially very productive but unemployed household has a higher probability not to be able to generate labor income while that productivity lasts. The mass of such households is small, however.

Different systematic responses of monetary policy are important as well. In order to demonstrate this, we study the transition to more accommodative monetary policy, as modeled by a higher response parameter to unemployment in the Taylor rule. In the baseline economy, this results in more stabilization of employment, which in turn leads households to reduce precautionary savings. It is the wealth-poorer households who benefit from this the most. For the wealth-rich, the opposite tends to be the case, the reason is that the reduced demand for assets reduces the price of these. This adversely affects those households with a high wealth to labor income ratio, that is, households who wish to reduce their asset holdings in order to smooth consumption. In one of the scenarios, which amounts to quadrupling the response coefficient to unemployment in the Taylor rule, the difference between the biggest winners and losers from such a policy is large, namely, 0.4 percentage points of life-time consumption. In this scenario, the great majority of households favor a change to more accommodative policy. We show that this may no longer be the case if inflation volatility leads to higher average markups (and thus lower average employment).

Relation to the literature

Our paper builds on three strands of literature. The first are incomplete-market general equilibrium models with infinitely-lived agents, aggregate uncertainty and flexible prices, such as Krusell and Smith (1998), and Ríos-Rull (1996). When discussing policy, this literature mainly focuses on fiscal policy; such as Heathcote (2005). We build on Krusell et al. (2010) and Nakajima (2012) who have have extended these models by Mortensen and Pissarides (1994)–type search and matching frictions in the labor-market, as we do. Costain and Reiter (2004) explore the insurance role of fiscal stabilization policy in that setup.

The second strand of literature focuses on the distributional effects of inflation in flexible price models with heterogenous agents. Erosa and Ventura (2002) and Albanesi (2007) analyze the distributional consequences of steady-state inflation within an incomplete markets model in which poorer households hold relatively more currency. Akyol (2004) studies a setup where in equilibrium the income rich hold more currency. We focus on the business cycle and cyclical monetary policy, instead. Heterogeneity also arises naturally in models of endogenous or exogenous limited asset-market participation, such as Alvarez et al. (2002) and Williamson (2008). Both Doepke and Schneider (2006) and Meh et al. (2010) focus on the distributional and aggregate effects of surprise inflation when agents hold nominal portfolios. Their focus is on the wealth redistribution channel that arises from what in their case, initially, is a pure redistribution due to unanticipated inflation. Our paper differs from the aforementioned in that monetary policy is not modeled primarily as a redistribution shock. In order to make this very clear, we abstract from modeling nominal portfolios altogether, building on the cashless limit of Woodford (1998). Rather, we focus on an environment in which monetary policy is conducted through changes in the nominal rate of interest. If prices are rigid, changes in the nominal interest rate translate into changes in the real rate of interest. In other words, monetary policy does not only *affect* the real rate, but is effective *because* it does so. This is not to say that wealth redistribution due to inflation could not be important. Rather, we wish to focus on a different channel through which monetary policy has distributional effects, and show that the effects are sizable even for apparently small differences in policies.

We follow the New Keynesian literature in assuming that there are nominal (goods price) rigidities. Monetary policy has a direct influence on the real rate of interest. Through this, in turn it affects aggregate demand. Aggregate demand can influence aggregate supply since markups are endogenous. The New Keynesian class of models has been been shown to be able to replicate salient features of the business cycle (Christiano et al. 2005 and Smets and Wouters 2007). Our model is placed within an active literature that assesses how labor markets characterized by search and matching frictions affect the properties of representative-household New Keynesian sticky price models; early contributions in this literature are Trigari (2009) and Walsh (2005). Galí (2010) provides a recent overview. When entertaining heterogeneity, the New Keynesian literature has typically resorted to the fiction of a fixed set of representative households who permanently differ in some characteristics. Within each class of types, all households then make the same decisions. Galí et al. (2007) study the transmission of government spending shocks when some households do participate in asset markets. 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. In Challe et al. (2013) households live in representative families when employed, but leave these temporarily when unemployed. In our model, instead, wealth heterogeneity can fluctuate endogenously even among employed households due incomplete asset markets and labor-market risk.

The endogeneity of idiosyncratic labor-market risk sets our paper apart from two other recent papers in the New Keynesian literature that allow for household heterogeneity. McKay and Reis (2012) study the role that automatic fiscal stabilizers have in shaping the business cycle. Bayer et al. (2014) study the effect of uncertainty shocks on economic activity in a model with temporarily limited participation. None of the two papers mentioned above focus on solving the model in a fully non-linear fashion. Instead, we show how to adapt the approximate-aggregation algorithm in Krusell and Smith (1998) to the current setting. We show that allowing for the nonlinearity is important quantitatively. One reason is that the non-linearity of the labor market at the aggregate level is important; for example, Jung and Kuester (2011) document that with search and matching frictions business cycle fluctuations can have substantial effects on average unemployment, output, and consumption, Petrosky-Nadeau and Kuehn (2011) show that hiring decisions can be strongly non-linear. We show that non-linearity can be essential for the Phillips curve as well.

The current paper is organized as follows. Section 2 introduces the model. Section 4 highlights the calibration and business cycle statistics. Section 5 highlights the effects of monetary shocks and, for comparison, technology shocks on the aggregate economy, and on measures of inequality. Section 6 discusses the welfare effects both of the aforementioned shocks and of a switch to more accommodative monetary policy. Section 7 provides robustness analysis. A final section concludes.

2 Model

The model economy is characterized by incomplete financial markets and heterogeneity in income and wealth as in Krusell and Smith (1998).[2] Households in our model face a zero-borrowing

[2] Gruber (1998) empirically finds that a higher replacement rate for unemployment insurance benefits is associated with a smaller drop in consumption expenditures upon unemployment, which suggests imperfect insurance against unemployment risks. The incomplete-market model is used to capture such imperfect insurance. We will calibrate the model such that the wealth distribution of the model matches the empirical

constraint. In order to endogenously capture earnings heterogeneity over the business cycle, we introduce Mortensen and Pissarides (1994) labor market search and matching frictions into the heterogeneous agent environment, following Nakajima (2012) and Krusell et al. (2010). In addition Households face idiosyncratic labor productivity shocks. Monopolistically competitive producers are subject to quadratic price adjustment costs. As a result, markups are endogenous, and in the short run, the economy becomes demand-driven. The portfolio allocation is done by a competitive mutual funds. Monetary policy is characterized by a Taylor (1993)-type rule that governs the nominal interest rate at which financial entities (representative mutual funds that own all the firms in the economy) can borrow or lend to each other. Due to rigid prices, the monetary authority can affect the real rate of interest and thereby economic activity (recall, markups are endogenous).

We model a cashless-limit economy; see Woodford (1998). The precise process of liquidity injection through which interest changes come to pass, therefore, is not modeled explicitly. Appendix E goes into greater detail. We make no attempt to consider optimal fiscal policy. Rather, we assume that the government balances its budget on a period-by-period basis, so that there is no government debt. This assumption reduces the number of state variables. At the same time, we are well aware that in incomplete markets models, government debt could help improve consumption insurance, as it does, for example, in Aiyagari and McGrattan (1998). As a result, we also abstract from seignorage as a source of funds for redistribution. Any distributional impacts of monetary policy that we find are conditional on these fiscal assumptions.

Next to the mutual funds, our model economy is characterized by four types of firms. First, capital producers invest in physical capital that they rent out in a competitive market. Second, there is a set of labor agencies that hire households in a frictional labor market. The labor agencies produce homogeneous labor services that they rent out in a competitive market. Third, intermediate-goods producers that are subject to price-adjustment costs rent labor and capital services and produce a differentiated good. Under monopolistic competition, they sell these goods to the fourth set of firms, representative competitive final goods firms; for the same structure linking the labor market and price-setting firms, see, for example Walsh (2005) or Trigari (2009).[3] We next turn to describing the model in more detail.

distribution, as an (indirect) way to discipline the degree of insurance available to U.S. households.

[3] Linking labor markets and price-setting decisions through competitive markets makes the model more tractable. Kuester (2010) makes the two decisions interdependent in a representative household setup with labor market frictions and shows that real rigidities arise.

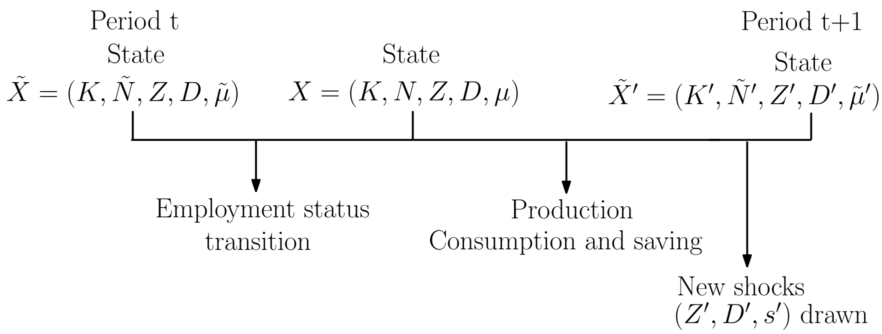

Figure 1: Timing of the model

2.1 States

We define the model recursively. In order to keep the notation short, define X as the vector of aggregate state variables at the time of production, where $X = (K, N, Z, D, \mu)$. K is the aggregate capital stock. N is aggregate employment. Two shocks drive the cyclical fluctuations of the economy: the aggregate productivity shock, Z, and the monetary policy shock, D.[4] Households are heterogeneous and characterized by a triplet (e, s, a). $e \in \{0, 1\}$ denotes the employment status: $e = 0$ indicates that a household is unemployed, while $e = 1$ indicates employment. A household works either full time or not at all. $s \in S$ represents the exogenously given skill level of a household, which follows a first order markov process. We assume that S is a finite set and denote the transition matrix by π. The probability of transiting from s to s' will be denoted as $\pi_{s,s'}$. $a \in A \subseteq \mathbb{R}$ denotes the share holdings of a household. As described above, all households have access to a mutual fund through which they can save for the future. $\mu(e, s, a)$ is the type distribution of households, defined as an element of a canonical Borel σ-algebra $\mathcal{M}$ defined over $\{0, 1\} \times S \times A$.

2.2 Timing

Figure 1 summarizes the timing assumptions of the model. Households enter the period knowing their own employment status, skill type, and the state of the aggregate economy at that time. For future reference, denote by $\widetilde{\mu}$ and $\widetilde{N}$ the type distribution and aggregate employment, respectively, at the beginning of the period, that is, before labor market transitions have occurred. Let $\widetilde{X} = (K, \widetilde{N}, Z, D, \widetilde{\mu})$ denote the corresponding state of the economy. Early in the period, previously employed households lose their jobs with exogenous probability λ. All non-

[4] That is, for reasons of computational tractability, we abstract from a number of other sources of business cycle shocks, particularly demand shocks or cost-push shocks that figure prominently in estimated New Keynesian models that adhere to the representative-agent paradigm; for example, Smets and Wouters (2007).

employed households search for jobs and firms post vacancies. After matching has taken place, taking into account the number of newly employed households, the aggregate state becomes $X = (K, N, Z, D, \mu)$. Then, households make consumption and savings decisions. Intermediate goods firms set their prices. Capital producers make their investment decisions. Production takes place. At the beginning of the next period, shocks to the households' skill levels are drawn, as are new aggregate shocks.

2.3 Households

Preferences are time-separable with time-discount factor $\beta \in (0,1)$ and period utility function $u(c)$ with standard properties. The functional form will be specified later. The following describes the problem of a household that is employed at the production, consumption, and saving stage $(e = 1)$ and has skill level s and asset-holdings a:

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

$$\text{s.t.} \qquad c + p_a(X)a' = \big(p_a(X) + d_a(X)\big)a + w(X)s\big(1 - \tau(X)\big), \tag{2}$$

Equation (1) is the household's Bellman equation. The household chooses consumption, c, and the number of shares of a mutual fund (explained further below) that it wants to carry into the next period, $a' \geq 0$, so as to maximize expected life-time utility subject to its budget constraint, (2). The household takes the job-finding rate, $f(\widetilde{X}')$, the price of shares, $p_a(X)$, dividends, $d_a(X)$, the wage, $w(X)$, and the payroll tax rate, $\tau(X)$, as given. Notice that the household is subject to a short-sell constraint with respect to share holdings, a'. The expectation operator $\mathbb{E}$ is taken with respect to the distribution of shocks going forward (Z', D', s', e'). In forming expectations, the household takes into account the law of motion of the aggregate states, $\widetilde{X}' = \widetilde{G}(X)$ and $X' = G(X)$.[5] A household that is currently employed will keep its job in the next period, too, with exogenous probability $1 - \lambda$. Households without a job always search for employment. The search intensity is constant. Even if separated from a job at the beginning of next period, with probability $f(\widetilde{X}')$ the household will find a new job within the same period. The job-finding rate, $f(\widetilde{X}')$, depends on the aggregate state of the economy in way that we describe further below.

[5] The law of motion of the aggregate states is a distribution function that depends on the realization of shocks in the beginning of the next period. This dependence on the shocks has been suppressed here.

If, in the next period, the household loses its job and does not find a new job immediately, its employment status changes to $e = 0$ and the household will go through a spell of unemployment. This happens with probability $\lambda(1 - f(\widetilde{X}'))$.

It may be useful, if only to fix the notation, to briefly describe the elements of the budget constraint: The right-hand side describes resources available to the household: the current *ex-dividend* value of the shares that the household owns, $p_a(X)a$, dividends associated with the shares, $d_a(X)a$, and after-tax labor income, $w(X)s(1 - \tau(X))$. $w(X)$ is the wage per efficiency unit and $\tau(X)$ is a constant proportional labor-income tax rate. The left-hand side of equation (2) describes how the household uses the resources for current consumption, c, and for purchasing shares that it carries into the next period, $p_a(X)a'$.

The problem of a household of skill level s and asset holdings a that is unemployed during the production phase ($e = 0$) is given by:

$$W(X, 0, s, a) = \max_{c,a' \geq 0} \left\{ u(c + Bs) + \beta \mathbb{E} \left[f(\widetilde{X}')W(X', 1, s', a') + \left(1 - f(\widetilde{X}')\right) W(X', 0, s', a') \right] \right\} \tag{3}$$

$$\text{s.t.} \qquad c + p_a(X)a' = (p_a(X) + d_a(X))\, a + bs, \tag{4}$$

The Bellman equation (3) reflects that next period the unemployed household transits into employment with state-dependent probability $f(\widetilde{X}')$ or otherwise remains unemployed. The budget constraint of the unemployed household mirrors that of the employed household. The only differences are that the unemployed household does not receive labor income but unemployment benefits and extra utility from leisure. b is the unemployment insurance benefit per efficiency unit of labor, while B is the value of leisure per efficiency unit.[6]

For future reference, let the optimal decision rules for consumption this period and share holdings for next period be denoted by $c = g_c(X, e, s, a)$ and $a' = g_a(X, e, s, a)$, respectively.

2.4 Aggregate Discount Factor

Households in the economy own all their wealth through equity claims on a mutual fund. Since households are heterogenous, the question arises how the mutual fund makes investment decisions. We assume that in pricing claims the mutual fund bases its decisions on the average of the individual households' intertemporal marginal rates of substitution of consumption, where the

[6] We make this assumption for simplicity as we assume that wage income is linear in productivity. The assumption could be for example rationalized by assuming that home production is linearly increasing in a workers productivity.

average is taken weighting by their end-of-period share holdings. More precisely, the stochastic discount factor is defined as follows:[7]

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

or, in short-hand notation:

$$
Q(X,X') = \beta \int_{\mathcal{M}} a' \frac{u_c(c')}{u_c(c)} \, d\mu'. \tag{5}
$$

Above, $u_c(c)$ marks the marginal utility of consumption. Krusell and Smith (1998) entertain an economy in which households invest directly in physical capital and firms only have static rental decisions to make. Like us, Carceles-Poveda and Coen-Pirani (2010) analyze an economy where, instead, firms make dynamic investment decisions. They show that value maximization by firms, where future values are assessed using (5), in an economy that otherwise resembles Krusell and Smith (1998), supports the same allocations as having the households invest into capital directly. In general, unanimity may no longer hold, however, see Carceles-Poveda and Coen-Pirani (2009). Favilukis et al. (2010) and Favilukis (2013) are other recent examples that apply discount factor (5).

Since the mutual funds own all non-financial firms and bonds in the economy, this is the discount factor that is relevant for the firms' respective decisions about investment, hiring, and pricing. The price of a share of the mutual fund, p_a, in turn, is competitively determined so as to equilibrate the demand for shares in the mutual fund to its supply.

2.5 Intermediate Good Producer

A unit mass of firms produces one type each of a differentiated good. The type is indexed by $j \in [0,1]$. Intermediate good producer j 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, $P_{j,-1}$. Price adjustment is

[7] Notice, that in equilibrium, knowledge of X and X' implies knowledge of $\widetilde{X}'$.

subject to Rotemberg (1982)-type quadratic adjustment costs. The producer's value is:

$$J_I(X_p) = \max_{P_j,\ell_j,k_j} y_j(X,P,P_j)\left(\frac{P_j}{P(X_p)}\right) - r(X)k_j - h(X)\ell_j - \frac{\psi}{2}\left(\frac{P_j}{P_{j,-1}} - \overline{\Pi}\right)^2 \bar{y} - \Xi + \mathbb{E}\left[Q(X,X')J_I(X',P_j)\right] \tag{6}$$

$$\text{s.t.} \quad y_j(X,P_j,P) = \left(\frac{P_j(X_p)}{P(X_p)}\right)^{-\epsilon} y(X), \tag{7}$$

$$y_j(X,P_j,P) = Zk_j^{\theta}\ell_j^{1-\theta}, \tag{8}$$

$y_j(X,P_j,P)$ is firm j's output. Constraint (7) ensures that output equals the demand for good j, with parameter $\epsilon > 1$ being the own-price elasticity of demand. $y(X)$ is the total output of final goods. Equation (8) is the production function of intermediate good j. $\Xi \geq 0$ is a fixed cost of production. $\bar{y}$ is steady-state output.[8] Parameter $\psi > 0$ indexes the extent of nominal rigidities. Price adjustment is costly only to the extent that the percentage price adjustment relative to last period differs from some fixed value $\overline{\Pi}$.

Total factor productivity (TFP), Z evolves according to:

$$\log(Z') = (1-\rho_Z)\log(\overline{Z}) + \rho_Z\log(Z) + \epsilon_Z, \text{ where } \epsilon_Z \text{ is i.i.d. } N(0,\sigma_Z^2), \rho_Z \in [0,1). \tag{9}$$

$\overline{Z}$ is the value of TFP in a non-stochastic steady state.

In equilibrium and imposing symmetry, all intermediate good producers will set the same price. The firms' problem (6) suggests that past prices of intermediate goods, $P_{j,-1}$, are state variables. The equilibrium conditions show, however, that – if the price level is not of interest in itself – keeping track of the past price is not necessary. The equilibrium condition of each firm can be completely described by the current aggregate rate of *inflation,* $\Pi(X)$, and other contemporaneous aggregate variables or the expectations of each of these.[9] In equilibrium, 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.

[8] This will be $1 + \Xi$ in our calibration.

[9] Note that if we, alternatively, were to model nominal rigidities using the Calvo sticky price setup, we would need to track a further state variable, namely, past price dispersion. Not having to do so is one advantage of the quadratic price adjustment cost framework.

2.6 Capital-Producing Sector

There is a representative capital-producing firm, the value of which can be characterized recursively as follows:

$$J_K(X,K) = \max_{v,i,K'} \left\{ r(X)Kv - i + \mathbb{E}\left[Q(X,X')J_K(X',K')\right] \right\} \tag{10}$$

$$\text{s.t.} \qquad K' = \big(1-\delta(v)\big)K + \zeta\left(\frac{i}{K}\right)K \tag{11}$$

The capital-producing firm produces a homogeneous good, called "capital services," that it sells to the intermediate goods sector at the competitive rate $r(X)$. Capital services are the product of the capital stock, K, and capacity utilization v. The rate of depreciation of the existing capital stock, $\delta(v)$, increases with utilization; see equation (39) below for the functional form that we assume. Next to deciding capacity utilization, 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. The functional form of $\zeta\left(\frac{i}{K}\right)$ will be introduced in equation (38).

The problem of the capital-producing firm characterizes aggregate investment $i(X)$, the aggregate utilization rate $v(X)$, and the aggregate capital stock in the next period $K'(X)$. In equilibrium, furthermore, $v(X)K = k(X)$ so that the amount of capital services produced in the capital-producing sector equals the demand of capital services by intermediate goods producers.

2.7 Labor Market

Labor agencies produce a homogeneous good called "labor services." They sell this to intermediate goods producers at the competitive rate of $h(X)$. Labor agencies may be matched with exactly one household or they are not matched. A labor agency that is already matched to a household produces an amount of labor services that is proportional to the skill level of the household that it employs. The value of that labor agency is:

$$J_L(X,s) = \big(h(X) - w(X)\big)s + \mathbb{E}\big[Q(X,X')(1-\lambda)J_L(X',s')\big]. \tag{12}$$

The first term reflects the fact that the labor agency pays the household a wage per efficiency unit of $w(X)$. Employment is subject to search frictions. As a result, there is wide set of wages that are bilaterally efficient *ex post*. In the current paper, we assume a functional form for the evolution of the wage per efficiency unit of labor over the business cycle. The functional form, $w(X)$, is presented in equation (40) in the calibration section. Note that this assumption is similar to assumptions found elsewhere in the New Keynesian literature; for example, Blanchard and Galí (2010). As in Gertler and Trigari (2009), we have checked that during all numerical simulations of the model neither the household nor the labor agencies would have been better off by ending a match. That is, wages stay in the bargaining set. The wage process will affect aggregate dynamics to the extent that it affects the value of hiring. The continuation value in the second term of equation (12) reflects the fact that only with probability $(1-\lambda)$ the match between a labor agency and its household will be producing in the next period. Otherwise, the match will be dissolved. The labor agency would need to hire a new household. The exposition here anticipates that due to free entry, the value of a labor agency that is not matched to a household is zero.

The labor market is characterized by search and matching frictions. Labor agencies that are not yet matched to a household can post a vacancy at cost κ. Labor firms cannot target their vacancies toward a certain skill level, nor can they condition on a prospective applicant's level of assets. The following free-entry condition governs the number of vacancies in equilibrium:

$$\kappa = \frac{M(\widetilde{X}, V)}{V} \int_{\mathcal{M}} J_L\left(\hat{G}(\widetilde{X}), s\right) d\,\mu. \tag{13}$$

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, compare equation (12), and the probability that an individual vacancy will be filled. The latter is given by the ratio of the aggregate number of new matches, M, to the aggregate number of vacancies, V.

Matches are formed according to the following matching function:

$$M(\widetilde{X}, V) = \frac{\left(U(\widetilde{X}) + \lambda N(\widetilde{X})\right) V}{\left(\left(U(\widetilde{X}) + \lambda N(\widetilde{X})\right)^{\alpha} + (V)^{\alpha}\right)^{\frac{1}{\alpha}}}, \quad \alpha > 0. \tag{14}$$

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), and V is the number of vacancies posted.

With the number of vacancies $V(\widetilde{X})$ being characterized by equation (13), the probability that a household without employment finds a new job is given by:

$$f(\widetilde{X}) = \frac{M(\widetilde{X}, V(\widetilde{X}))}{U(\widetilde{X}) + \lambda N(\widetilde{X})}. \tag{15}$$

This probability is the same for each household, regardless of its skill level, wealth, or, indeed, unemployment duration. Matching function (14), taken from den Haan et al. (2000), ensures that job finding rate and job filling rate are well-defined probabilities.

2.8 Final-Goods Producers

Final goods can be used for consumption, investment and vacancy creation. They are produced by representative competitive final goods firms. These transform the differentiated inputs y_j, $j \in [0, 1]$, into a homogenous output. The final good producer takes each input price $P_j(X_p)$ as given. The problem of the representative final good producer is to

$$\max_{y,(y_j)_{j\in[0,1]}} P(X_p)y - \int_0^1 P_j(X_p)y_j dj \tag{16}$$

$$\text{s.t.} \quad y = \left(\int_0^1 y_j^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}}. \tag{17}$$

The optimal decision translates into the demand function anticipated in (7).

Next, we describe the functioning of the mutual fund, which is central to the way in which monetary policy decisions affect aggregate activity.

2.9 Mutual Fund

For the sake of tractability, we abstract from a portfolio choice by the individual households. Rather, we assume that they delegate financial management to a representative mutual fund. The households, therefore, only indirectly own the firms described above, namely, through their share-holdings in the mutual funds. These shares in the mutual funds are the only assets that households can hold. Mutual fund shares are traded in a competitive market at (ex-dividend) price p_a.[10]

There are five types of assets in the economy that the mutual funds trade among each other: equity of final goods producers, intermediate goods producers, and producers of capital and labor

[10] Due to adverse selection and enforcement costs, unemployment insurance typically is not provided by private markets. Thus, we quite realistically assume that insurance markets are incomplete in the sense that the mutual fund or individual households do not sell unemployment or salary insurance.

services, plus unconditional one-period nominal inside debt. As is a standard assumption in New Keynesian models, the central bank is assumed to control the rate of return on these. As is also common, but here mainly done for tractability, we abstract from an effect of central bank operations on the actual amount of outstanding private-sector debt. Since prices are sticky, by setting the nominal rate of return, 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. In particular, equilibrium in the mutual funds market requires that all assets be priced according to the mutual fund sector's discount factor, (5), with the nominal bonds being in zero net supply.

To summarize, the mutual funds can lend and borrow using safe one-period pure-discount bonds that are traded in a centralized market. The equilibrium price, p_b, of these bonds is determined by the funds' discount factor as follows:

$$p_b(X) = \mathbb{E}\left[Q(X, X')\frac{1}{\Pi(X')}\right], \tag{18}$$

where $\Pi(X)$ is the gross rate of inflation. This, for the bond investment decision, yields a standard Euler equation (now for the mutual fund rather than the representative household)

$$1 = \mathbb{E}\left[Q(X, X')\frac{R(X)}{\Pi(X')}\right]. \tag{19}$$

The gross nominal interest rate $R(X) := 1/p_b(X)$ is assumed to be the central bank's instrument.[11] The values of the other assets that the mutual funds hold, namely J_I, J_K, and J_L, have been described in the previous subsections. The equilibrium value of final goods firms is equal to zero since they face both competitive product and factor markets.

We do not, currently, allow the mutual fund or the other firms in the economy to retain earnings. Rather, all the profits that are not reinvested are distributed to the share holders of the mutual funds in the form of dividends. Let $d_a(X)$ denote the dividends per share. These are given by the following:

$$\begin{aligned} d_a(X) \quad = \quad & \int_0^1 \left[y_j(X)\tfrac{P_j(X)}{P(X)} - r(X)k_j(X) - h(X)\ell_j(X) - \Xi - \tfrac{\psi}{2}\left(\tfrac{P_j}{P_{j,-1}} - \overline{\Pi}\right)^2 \bar{y}\right] \, dj \\ + \quad & r(X)K(X)v(X) - i(X) \\ + \quad & \int_{\mathcal{M}} (h(X) - w(X))s \; d\,\mu - \kappa V(\widetilde{X}). \end{aligned} \tag{20}$$

[11] We abstract from the costs of holding non-interest bearing currency, and instead focus on what has become known as the cashless limit. Appendix E spells out how the central bank can control the interest rate even if the amount of cash is small.

On the right-hand side, the first line shows the profits of the intermediate goods firms. The second line shows the profits in the capital services sector. The third, and final line, marks the profits in the labor services sector. The term in the integral refers to the profits of labor agencies that are matched to a household when production takes place. The second, negative, part is the costs that labor agencies without workers spend on posting vacancies.[12]

2.10 Central Bank

The literature finds that Taylor (1993)-type rules are a good representation of monetary policy-making in recent decades. The central bank adjusts the gross nominal interest rate, R, according to

$$\log\left(\frac{R(X)}{\overline{R}^{\text{CB}}}\right) = \phi_{\Pi}\log\left(\frac{\Pi(X)}{\overline{\Pi}^{\text{CB}}}\right) - \phi_u\left(U(X) - \overline{U}^{\text{ CB}}\right) + D, \tag{21}$$

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 $\phi_u \geq 0$), following Blanchard and Galí (2010). The superscripts "CB" here signal that in principle, these targets are choices for the central bank. In the baseline, we will assume the inflation target is two percent per year and that the other targets are set to the constant value of the corresponding nonstochastic steady state. Often, estimated Taylor rules also allow for "intrinsic policy inertia," that is, a term involving last period's interest rate on the right-hand side of equation (21) in order to capture persistent deviations of the federal funds rate from the "desired" funds rate as specified above; compare, for example, Clarida et al. (1998). Though the induced history persistence would likely be desirable from a normative perspective (see Woodford (2003)), the extent to which such policy inertia reflects actual policy-making or to which it reflects missing information (and should thus be captured by correlated errors) is subject to debate; Rudebusch (2006) provides a critical appraisal. While we do not wish to take a specific stand on the discussion, here we assume that there is no intrinsic policy inertia. The nominal interest rate is hit by persistent monetary policy shocks that capture persistent deviations from typical behavior. We take these shocks, D, to follow a first-order autoregressive

[12] Since, for each mutual fund, bond holdings are zero in equilibrium, income from risk-free bonds has been ignored in equation (20). Similarly, we omit profits in the final goods sector, which in equilibrium are equal to zero, too.

process:

$$\log(D') = \rho_D \log(D) + \epsilon_D, \text{ where } \epsilon_D \text{ is i.i.d. } N(0, \sigma_D^2)\ , \rho_D \in [0, 1). \tag{22}$$

2.11 Fiscal Authority

The government runs a balanced-budget policy, its budget constraint being:

$$\int_{\mathcal{M}} \mathbb{1}_{e=0}\, bs\ d\mu = \tau(X) \int_{\mathcal{M}} \mathbb{1}_{e=1}\, w(X)s\ d\mu. \tag{23}$$

The government pays unemployment insurance benefits (left-hand side). The cost is b per efficiency unit of labor for each unemployed household ($\mathbb{1}$ marks the indicator function). Unemployment benefits are financed by a proportional tax $\tau(X)$ on the labor income of employed households (right-hand side). The assumption that the government does not have debt is not necessarily innocuous, in that by providing government debt, the government could help agents in the economy to ease the borrowing constraint; see, for example, Aiyagari and McGrattan (1998). More innocuous, in the current model, is the way in which the government finances unemployment benefits. The proportional tax on labor income will have an effect on resources available to employed households. It will not, however, affect directly their labor supply decision (search effort is assumed to be exogenous). Neither will it affect the firms' costs, by virtue of our assumption as regards the wage rule (40).

2.12 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 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 (11) :

$$K'(X) = \left[1 - \delta\big(v(X)\big)\right] K + \zeta \left(\frac{i(X)}{K}\right) K \tag{24}$$

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

$$N(X) = (1-\lambda)N(\widetilde{X}) + M(\widetilde{X}, V(\widetilde{X})). \tag{25}$$

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:

$$N'(\widetilde{X}') = N(X). \tag{26}$$

Last, we need to keep track of the type distribution of households. Remember that, at the beginning of a period, the type distribution is $\widetilde{\mu}(\widetilde{e}, s, a)$, 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 $\mu(e, s, a)$. The laws of motion of $\widetilde{\mu}$ and μ are linked as follows:

$$\mu(1, s, a) = f(\widetilde{X})\widetilde{\mu}(0, s, a) + [1 - \lambda + \lambda f(\widetilde{X})]\, \widetilde{\mu}(1, s, a), \tag{27}$$

$$\mu(0, s, a) = [1 - f(\widetilde{X})]\widetilde{\mu}(0, s, a) + \lambda[1 - f(\widetilde{X})]\, \widetilde{\mu}(1, s, a), \tag{28}$$

Notice that, between $\widetilde{\mu}$ 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 the following:

$$\widetilde{\mu}'(\overline{e}, \overline{s}, \overline{A}) = \sum_{s \in S} \pi_{s,\overline{s}} \int_{\mathcal{M}} \mathbb{1}_{e=\overline{e}}\, \mathbb{1}_{s}\, \mathbb{1}_{g_a(X,\overline{e},s,a)\in \bar{A}}\ d\ \mu(e, s, a), \tag{29}$$

with $\overline{A} \in A$ being a subset of the space of the share holdings and $\overline{e}$, $\overline{s}$ being individual states in $\{0, 1\}$ and S, respectively. $\pi_{s,\overline{s}}$ marks the probability to transit from skill state s to state $\overline{s}$ at the end of the period.

2.13 Market Clearing and Equilibrium

There are six markets operating in the model – final goods, intermediate goods, labor services, capital services, share of mutual funds, and inside bonds. Below are their market clearing conditions. The final goods market clears if

$$y(X) = \int_{\mathcal{M}} g_c(X, e, s, a)\ d\ \mu + i(X) + \kappa V(\widetilde{X}) + \int_0^1 \left[\Xi + \frac{\psi}{2}\left(\frac{P_j}{P_{j,-1}} - \overline{\Pi}\right)^2 \overline{y}\right]\ dj, \tag{30}$$

where the first two terms on the right-hand side are aggregate consumption and investment, respectively, and the other two terms refer to price adjustment costs and vacancy posting costs, respectively. [13] By equation (**??**) and (8), the markets for all intermediate goods clear whenever

$$y(X) = Zk_j^{\theta} l_j^{1-\theta}, \forall j \in [0,1]. \tag{31}$$

The market for labor services clears if

$$\int_{\mathcal{M}} s\mathbb{1}_{e=1} \, d\, \mu = \int_0^1 \ell_j \, dj. \tag{32}$$

The market for capital services clears if

$$v(X)K = \int_0^1 k_j \, dj. \tag{33}$$

The stock market (the market for shares of the mutual funds) clears if

$$\int_{\mathcal{M}} g_a(X,e,s,a) \, d\, \mu = 1. \tag{34}$$

Last, the (within mutual funds) bond market clears if inside bonds are in zero net supply. With this, we can define the recursive equilibrium in the model as follows.

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

[13] We view price adjustment and fixed costs as intermediate inputs. Therefore, whenever we report GDP, we use $y(X)$ net of these costs.

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 (5).*

7. *$d_a(X)$ satisfies the flow budget constraint of mutual funds (20).*

8. *The wage per efficiency unit of labor is given exogenously by $w(X)$ (40).*

9. *The labor tax $\tau(X)$ satisfies the government budget constraint (23).*

10. *The nominal interest rate $R(X)$ satisfies the Taylor rule (21).*

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.*

3 Calibration

The model is solved numerically. One way to approximate the model would be to linearize the aggregate dynamics. McKay and Reis (2012) follow this approach. Here, we rather a solution method based on Krusell and Smith (1998) and Reiter (2010). We choose this algorithm so as to be able to allow for non-linearity in the aggregate dynamics. We consider this important because search and matching frictions in the labor market can generate a link between aggregate fluctuation and average employment. See, for example, Jung and Kuester (2011) and Hairault et al. (2010). We will document that the same is true for the New Keynesian Phillips curve. A detailed description of the solution algorithm can be found in Appendix C. Next, we turn toward the calibration.

The purpose of the paper is to ascertain to what extent monetary policy in the U.S. may have distributional consequences through the channels that we model. Toward that end, we first seek to calibrate the model to the U.S. economy. In later sections, we then ask quantitatively by how much monetary policy affects inequality in this model economy. The calibration sample ranges from 1984Q1 to 2008Q3. One period in the model is a quarter. Given the numerical burden of the solution algorithm, we cannot use the simulated method of moments to directly match the heterogenous-agent model to long-run moments. Instead, we opt for a compromise: we calibrate several parameters so that the steady state in the model without aggregate shocks ("steady state" henceforth) matches long-run averages in the data. We set other parameters with a view toward targeting second moments in the data. When we target second moments in the data, owing to the computational costs, we choose parameters so as to match the second moments in the representative agent counterpart of the nonlinear model. We then use these parameters in the heterogenous-agent model. Tables 5 and 6 summarize the values we choose for the calibrated parameters. We will discuss these choices next.

3.1 Households

The period utility function is $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, where we set $\sigma = 1.5$, a standard value; for example, Smets and Wouters (2007). The time-discount factor, β, is calibrated jointly with other parameters to obtain an annualized real return on saving of 4 percent in the steady state. In the paper, we seek to investigate the implications of monetary policy for households with different levels of wealth. We, therefore, have to capture the distribution of wealth in the U.S. economy. Toward that aim, we calibrate the stochastic process for the idiosyncratic productivity shock. In particular, we use four discrete skill levels: $s \in S = \{s_1, s_2, s_3, s_4\}$. $\{s_1, s_2, s_3\}$ capture the productivity of "normal" households, with s_1 being 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 use the latter group of households in order to capture the skewed distribution of wealth in the U.S. economy; see Díaz-Giménez et al. (2011).

We parameterize the skill transitions by ensuring that in the steady state the model accounts for the following five targets: (i) 1 percent of the households are super-skilled; (ii) the Gini index of wealth is 0.82; (iii) the proportion of households that are borrowing-constrained is 0.10; (iv) the Gini index of earnings is 0.64; and (v) the autocorrelation of annual earnings of continuously employed workers is 0.9. The first target is motivated by the fact that the dynamics of individual earnings in the Panel Study of Income Dynamics (PSID) is reasonably replicated by an AR(1) process. We will use such a process for transitions between the normal skills. The PSID is known to under-sample the highest-income or highest-wealth households, which pins down the size of the super-skilled group. Targets (ii) to (iv) are calculated using the 2007 Survey of Consumer Finances. The last target (v) is motivated by existing empirical estimates of annual earnings

Table 1: Calibrated Parameters

Parameter	Value	Description
Households		
σ	1.5	Relative risk aversion.
β	0.974	Time-discount factor.
$\pi_{s,s'}$	see Table 6	Skill transition probabilities.
s_1	0.141	Productivity low-skilled.
s_2	0.437	Productivity medium-skilled.
s_3	1.349	Productivity high-skilled.
s_4	36.41	Productivity super-skilled.
Capital services		
ζ_0	0.676	Parameter for capital adjustment cost.
ζ_1	0.125	Parameter for capital adjustment cost.
ζ_2	–0.0021	Parameter for capital adjustment cost.
δ_0	0.015	Parameter for utilization cost function.
δ_1	1.673	Parameter for utilization cost function.
Intermediate goods		
ϵ	4.00	Elasticity of substitution across intermediate goods
θ	0.274	Exponent on capital in intermediate good production.
ψ	57.12	Slope of price adjustment cost.
$\overline{\Pi}$	1.005	Full indexation to an annualized inflation rate of 2 percent.
Ξ	0.220	Fixed cost of operation.
ρ_Z	0.950	Persistence of total factor productivity shock.
$\sigma_Z * 100$	0.502	Standard deviation of total factor productivity shock.
$\bar{Z}$	0.678	Mean of total factor productivity shock.
Labor services and labor market		
λ	0.100	Separation rate
α	1.677	Matching elasticity w.r.t. number of searchers.
$\overline{w}$	0.681	Average wage per efficiency unit.
ϵ_w	0.450	Wage elasticity w.r.t. output.
κ	0.166	Vacancy posting cost.
Monetary policy and fiscal policy		
$\overline{\Pi}^{\text{CB}}$	1.005	Target gross inflation rate per quarter.
$\overline{u}^{\text{CB}}$	0.06	Target for unemployment rate.
$\overline{R}^{\text{CB}}$	1.015	Steady-state risk-free nominal interest rate per quarter.
ϕ_Π	1.500	Responsiveness of policy rate to inflation.
ϕ_u	0.158	Responsiveness of policy rate to unemployment.
ρ_D	0.700	Persistence of monetary policy shock.
$\sigma_D * 100$	0.103	Standard deviation of monetary policy shock
b	$0.435 * \overline{w}$	Unemployment insurance benefits per efficiency unit.
B	$0.265 * \overline{w}$	Leisure value per efficiency unit.

Notes: The table shows the calibrated parameters at the quarterly frequency. See the main text for explanations and details regarding calibration targets.

persistence, most of which range between 0.9 and 1.[14]

This gives us five targets for the skill transitions. 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 by Adda and Cooper (2003). As regards transitions to or from the super-skilled state, we assume symmetry. Namely 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 each 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 6 reports the resulting transition probabilities per quarter. Figure 14 in Appendix D shows

Table 2: Skill Transition Matrix

		future			
		s_1	s_2	s_3	s_4
today	s_1	0.9733	0.0260	0.0000	0.0007
	s_2	0.0260	0.9474	0.0260	0.0007
	s_3	0.0000	0.0260	0.9733	0.0007
	s_4	0.0223	0.0223	0.0223	0.9331

Notes: Transition probabilities per quarter, π_{s_i,s_j}, across skill groups. s_1 : lowest skill group, s_4 : highest skill group. Due to rounding, rows may not sum exactly to 1.

that the calibrated model closely matches the wealth distribution in the U.S. economy. In the same appendix, Table 18 shows that the model matches the main feature originating from this observation, namely, that "Wall Street" (the five percent wealth-richest households) derive a large share of income from financial wealth, whereas "Main Street" (the remaining 95 percent) does not.

[14] See for example the review in Nakajima (2012).

3.2 Capital-Producing Sector

The form of the capital adjustment costs is specified following van Binsbergen et al. (2012) as:[15]

$$\zeta\left(\frac{i}{K}\right) = \zeta_0\left(\frac{i}{K}\right)^{1-\zeta_1} + \zeta_2. \tag{35}$$

With regard to the parameters, we set the curvature parameter ζ_1 such that the volatility of hp-filtered log consumption (in the representative-agent version of the model with $\beta = 0.99$) is 0.77 as in the data. We target consumption volatility rather than investment volatility since the former is what is relevant for welfare. As is standard in the DSGE literature, the remaining parameters in equation (38) are pinned down by requiring that in the steady state adjustment costs do not affect behavior, so that $\zeta\left(\frac{i}{K}\right)K = i$ and $\zeta'\left(\frac{i}{K}\right)K = 1$. See the second block of rows in Table 5 for the corresponding values. The depreciation rate of capital follows the functional form specified by Greenwood et al. (1988), namely:

$$\delta(v) = \delta_0(v)^{\delta_1}. \tag{36}$$

We target a steady-state depreciation rate of $\delta_0 = 0.015$ (6 percent at annual rates) and choose a value of δ_1 such that the utilization rate is equal to 1 in the steady-state.

3.3 Intermediate Good Producer

Turning to the intermediate goods producers, we set the elasticity of substitution across intermediate goods to $\epsilon = 4$, implying a steady-state markup of 30 percent.[16] A low value for the elasticity makes sure that, numerically, we can entertain a Phillips curve with firmspecific price adjustment costs in the robustness section. It also makes the model numerically more stable toward a wider range of parameters of the monetary policy rule. 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 10. Parameter ψ governs the price adjustment cost. We set it to 57.12. 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 complemen-

[15] The DSGE literature, following Christiano et al. (2005), typically entertains *investment* adjustment costs rather than *capital* adjustment costs. The former leads to a more drawn-out response of investment to shocks. The specification used here saves one state variable.

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

tarities) when prices lasted for 5 quarters on average. We set the reference level of inflation to $\overline{\Pi} = 1.005$ meaning there is complete indexation to a steady inflation rate of 2 percent per year. 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, $\rho_Z = 0.95$ is standard. The standard deviation of the TFP shock ($\sigma_Z = 0.005$) was calibrated such that GDP in the representative-agent version of the model (once H-P-filtered) has the same standard deviation as GDP in the data.

3.4 Labor Market

We set a separation rate of $\lambda = 0.10$, 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 6 percent, this results in a value of $\alpha = 1.677$. 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 $\kappa = 0.166$. Any wage that leaves both firms and workers with a positive surplus from continuing the match will be an equilibrium wage. We postulate that the wage evolves according to

$$\log w(X) - \log \overline{w} = \epsilon_w \cdot \left[\log \left(\frac{GDP(X)}{N(X)} \right) - \log \left(\frac{\overline{GDP}}{\overline{N}} \right) \right], \tag{37}$$

thus being linked to labor productivity. Here $\overline{w}$ is the steady-state wage level. As before, $GDP(X)$ is defined as production $y(X)$ net of capital adjustment costs and fixed costs, both of which we see as intermediate inputs. $\epsilon_w \in [0,1]$ represents the elasticity of the wage with respect to measured labor productivity. Values of $\epsilon_w < 1$ can be interpreted as reflecting "wage stickiness."[17] Following Hagedorn and Manovskii (2008), we target $\epsilon_w = 0.45$. We set the steady-state wage per efficiency unit of labor to $\overline{w} = 0.681$. This generates a labor share of 64 percent in GDP.

These choices imply that this is a small-surplus calibration on the side of firms, which is required to make unemployment fluctuate over the cycle, see Hagedorn and Manovskii (2008). The labor firms distribute most of their revenues to their workers. The steady-state period profit equals 3.6 percent of revenue $(hs - ws)/(hs) = 0.0316$. The private surplus of the worker relative to unemployment is large. In particular, $(ws(1-\tau) - (b+B)s)/(b+B)s = 0.39$, meaning that wages exceed unemployment benefits (which are meant to include the value of leisure) by

[17] In the current model, wage stickiness serves to amplify labor market fluctuations, as in Shimer (2004) and Hall (2005). Wage stickiness does not necessarily imply, however, that the marginal costs of price-setting firms are rigid, see Krause and Lubik (2007). In particular, the price of labor services rather than wages feeds into marginal costs. The former is a mix of the wage and the value of having a household employed now and in the future. Therefore, marginal costs tend to be less rigid than the wage.

39 percent. Table 7 shows the surplus of the firm (as percent of revenue) and the

Table 3: Surplus of firm and worker

	skill level today			
	s_1	s_2	s_3	s_4
Surplus of the firm	78.861	48.909	32.633	21.671
Surplus of the worker				
no wealth	0.871	0.744	0.822	3.975
median wealth	0.012	0.033	0.094	1.359
99th percentile of wealth	0.002	0.007	0.020	0.422

Notes: Surplus of the firm and the worker, expressed in percentages of revenue and unemployment benefits, respectively. Surplus of the firm: $J_L(\overline{X}, s)/(h(\overline{X})\, s) * 100$, s is the skill level of the matched worker. Surplus of the worker: $(W(\overline{X}, 1, s, a) - W(\overline{X}, 0, s, a))/|W(\overline{X}, 0, s, a)|$.

surplus of the worker from employment (as percent of the steady-state unemployment benefits) for different skill and asset levels. Our baseline calibration features both wage rigidity and exogenous separations. At the same time, unemployed workers have an acceptance probability of one, once matched with a firm. We have checked numerically that the wage always stays within the bargaining set. For the firm, we check that the value of the firm never becomes negative both in the simulation as well as for the policy function. For the worker, after tax wages never fall nearly enough to reach a 25 percent loss (the gap between the replacement rate and the wage in steady state), so employment is always preferred even over the business cycle. Since, throughout, we assume that wages and benefits are proportional to skills, that is enough to ensure that workers always want to work at the given wage.

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. Our model does not have mechanisms to explain the equity premium. The rate $\overline{R}^{\text{CB}}$ used in the Taylor rule is chosen with a target for the steady-state real rate of return of 4 percent in mind. The response of the policy rate to inflation in the Taylor rule is set at $\phi_\Pi = 1.5$. The response parameter to unemployment is set to $\phi_u = 0.158$. We determine this value to match the volatility of hp-filtered log unemployment in data and model (hp-weight 1,600). Using an *ad hoc* Okun's law with coefficient of 0.5, this choice for ϕ_u maps into roughly half the value of the original Taylor (1993)-rule coefficient on output. The target level for the unemployment rate, $\overline{U}^{\text{CB}}$, is set to the steady-state level of unemployment (0.06). The New Keynesian literature often allows for "policy inertia" by having a lagged federal funds rate on the right-hand side of the Taylor rule. A typical value of the coefficient on the lagged interest rate is 0.7; for example, Clarida et al. (2000). Such a response would considerably complicate the computation since the lagged policy rate would be an aggregate state variable. In the current paper, instead, we opt for inducing the interest rate persistence through autocorrelation of the monetary policy shock, the persistence of which we set at $\rho_D = 0.7$. The standard deviation of the monetary policy shock, σ_D, is calibrated so that the model generates a volatility of hp-filtered log inflation rather close to the data. Absent monetary policy shocks, the model produces too little volatility in inflation and the nominal interest rate. The standard deviation of the monetary policy shock, σ_D, is calibrated so that the model generates a reasonable volatility of hp-filtered log inflation and the interest rate compared with the data, while still retaining a reasonable size for these shocks. We set $\sigma_D = 0.001$ so that a one-standard deviation monetary shock all else equal amounts to a 40 bps increase in the (annualized) nominal interest rate.

3.6 Government

With regard to the unemployment insurance system, we target a replacement rate (in the steady state) of 43.5 percent of earnings while setting the value of leisure to 26.5 percent. The total flow value of unemployment is 70 percent, which is close to the value argued for in Hall and Milgrom (2008). The value helps generate a realistic number of borrowing-constrained households without complicating the model by adding, for example, heterogeneity in discount factors or by choosing more extreme values for other parameters. 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 2.78 percent.

3.7 Business Cycle Statistics

This section reports how well the model matches the business cycle facts for the U.S. economy. The data are quarterly or quarterly averages of monthly data. Where applicable they are seasonally adjusted. Unless noted otherwise, their source is the St. Louis Fed's FRED II database. Nominal variables are deflated by the GDP deflator, which we also use for our measure of inflation, Π. Personal consumption expenditures, c, are from the national accounts. They include total durable and nondurable 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.

There is an ongoing discussion as to how the non-standard measures of monetary accommodation that the Federal Reserve implemented in the last recession have affected the economy and if and how they can be mapped into Taylor-type rules. We, therefore, want to steer clear of that episode and let our comparison sample end before the lower bound becomes binding. Accordingly, we focus on the period of the Great Moderation, from 1984Q1 to 2008Q3.

Table 8 compares second moments implied by the model and the data. In order to make data and model comparable, we report moments for the percentage deviation from trend for both the model-generated and actual time series. The trend was derived using the Hodrick-Prescott (H-P) filter with smoothing parameter 1,600 on the natural logarithm of the respective time series.

The first three columns report second moments in the baseline model with heterogeneous agents. The second block of three columns reports the second moments of the representative-agent version of the model. These moments are included here for two reasons. First, as discussed above, we use the representative agent version 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 succeeds in replicating the main cyclical properties of GDP and its components, see the first four rows of Table 8. Consumption is less volatile than GDP and procyclical. Investment is considerably more volatile. Capacity utilization, too, is procyclical. It is less volatile in the model, however, than in the data. The heterogeneous households imply that aggregate consumption fluctuates more than under representative agents whereas investment fluctuates by less. The second block of rows in Table 8 compares business cycle properties of the labor market in the model and the data. The model succeeds in replicating the key cyclical properties of the labor market data: Unemployment and vacancies are both highly volatile. Unemployment is strongly countercyclical. The third block of Table 8 regards productivity and prices. The model matches the properties of labor productivity well, apart from implying - again – somewhat lower persistence. As in the data, the wage per employed household is less volatile than output.

The model economies are non-linear. Table 19 in Appendix F shows the mean of each variable (based on 1,000,000 simulation periods) and compares that to the non-stochastic steady state.

Table 4: Model vs. data – second moments

	Model						Data		
	heterog. hh.			represent. hh.			1984Q1-2008Q3		
	Std	Corr	AR(1)	Std	Corr	AR(1)	Std	Corr	AR(1)
Output and components									
GDP (GDP)	1.35	1.00	0.67	1.32	1.00	0.67	1.36	1.00	0.92
Consumption (c)	0.86	0.99	0.72	0.74	0.99	0.72	0.77	0.84	0.82
Investment (i)	3.56	0.99	0.72	4.08	0.99	0.72	4.77	0.93	0.85
Capacity utilization (v)	0.55	0.82	0.34	0.51	0.79	0.32	1.87	0.75	0.91
Labor market									
Employment $N(X)$	0.52	0.94	0.68	0.51	0.94	0.68	0.50	0.81	0.94
Unemployment $U(X)$	8.63	-0.93	0.68	8.52	-0.92	0.69	8.48	-0.84	0.94
Vacancies (V)	6.99	0.74	0.10	6.83	0.74	0.11	10.05	0.89	0.91
Job finding rate (f)	4.22	0.90	0.41	4.10	0.90	0.41	5.84	0.75	0.78
Productivity and Prices									
$GDP(X)/N(X)$	0.88	0.98	0.67	0.86	0.98	0.66	0.93	0.89	0.84
Wage $W(X)$	0.40	0.98	0.67	0.39	0.98	0.66	0.89	0.49	0.84
Inflation Π[1]	0.64	-0.83	0.73	0.65	-0.85	0.73	0.68	0.22	0.16
Nominal rate R[1]	0.66	-0.95	0.77	0.69	-0.97	0.77	1.16	0.60	0.92

Notes: The table compares moments of the data and two variants of the model (heterogenous households, representative households). The model data are from 1,000,000 periods of simulations of the model. Each simulation is initialized with 500 periods of simulations that are dropped for the computation of the moments. In each case, we take the natural log of the data. Reported is 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. 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 autoregression coefficient. [1]: the nominal interest rate and inflation are reported in annualized percentage points. Some of the moments in the representative agent model where targeted based on 10,000 simulation runs. These targets are hit by the parameterization. The moments reported here may differ marginally from the target since the table shows moments for 1,000,000 runs.

In the baseline, the non-linearities are hardly visible in the means.

4 Calibration

The model is solved numerically. One way to approximate the model would be to linearize the aggregate dynamics. McKay and Reis (2012) follow this approach. Here, we rather a solution method based on Krusell and Smith (1998) and Reiter (2010). We choose this algorithm so as to be able to allow for non-linearity in the aggregate dynamics. We consider this important because search and matching frictions in the labor market can generate a link between aggregate fluctuation and average employment. See, for example, Jung and Kuester (2011) and Hairault et al. (2010). We will document that the same is true for the New Keynesian Phillips curve. A detailed description of the solution algorithm can be found in Appendix C. Next, we turn toward the calibration.

The purpose of the paper is to ascertain to what extent monetary policy in the U.S. may have distributional consequences through the channels that we model. Toward that end, we first seek to calibrate the model to the U.S. economy. In later sections, we then ask quantitatively by how much monetary policy affects inequality in this model economy. The calibration sample ranges from 1984Q1 to 2008Q3. One period in the model is a quarter. Given the numerical burden of the solution algorithm, we cannot use the simulated method of moments to directly match the heterogenous-agent model to long-run moments. Instead, we opt for a compromise: we calibrate several parameters so that the steady state in the model without aggregate shocks ("steady state" henceforth) matches long-run averages in the data. We set other parameters with a view toward targeting second moments in the data. When we target second moments in the data, owing to the computational costs, we choose parameters so as to match the second moments in the representative agent counterpart of the nonlinear model. We then use these parameters in the heterogenous-agent model. Tables 5 and 6 summarize the values we choose for the calibrated parameters. We will discuss these choices next.

4.1 Households

The period utility function is $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, where we set $\sigma = 1.5$, a standard value; for example, Smets and Wouters (2007). The time-discount factor, β, is calibrated jointly with other parameters to obtain an annualized real return on saving of 4 percent in the steady state. In the paper, we seek to investigate the implications of monetary policy for households with different levels of wealth. We, therefore, have to capture the distribution of wealth in the U.S. economy. Toward that aim, we calibrate the stochastic process for the idiosyncratic productivity shock.

Table 5: Calibrated Parameters

Parameter	Value	Description
Households		
σ	1.5	Relative risk aversion.
β	0.974	Time-discount factor.
$\pi_{s,s'}$	see Table 6	Skill transition probabilities.
s_1	0.141	Productivity low-skilled.
s_2	0.437	Productivity medium-skilled.
s_3	1.349	Productivity high-skilled.
s_4	36.41	Productivity super-skilled.
Capital services		
ζ_0	0.676	Parameter for capital adjustment cost.
ζ_1	0.125	Parameter for capital adjustment cost.
ζ_2	–0.0021	Parameter for capital adjustment cost.
δ_0	0.015	Parameter for utilization cost function.
δ_1	1.673	Parameter for utilization cost function.
Intermediate goods		
ϵ	4.00	Elasticity of substitution across intermediate goods
θ	0.274	Exponent on capital in intermediate good production.
ψ	57.12	Slope of price adjustment cost.
$\overline{\Pi}$	1.005	Full indexation to an annualized inflation rate of 2 percent.
Ξ	0.220	Fixed cost of operation.
ρ_Z	0.950	Persistence of total factor productivity shock.
$\sigma_Z * 100$	0.502	Standard deviation of total factor productivity shock.
$\bar{Z}$	0.678	Mean of total factor productivity shock.
Labor services and labor market		
λ	0.100	Separation rate
α	1.677	Matching elasticity w.r.t. number of searchers.
$\overline{w}$	0.681	Average wage per efficiency unit.
ϵ_w	0.450	Wage elasticity w.r.t. output.
κ	0.166	Vacancy posting cost.
Monetary policy and fiscal policy		
$\overline{\Pi}^{\text{CB}}$	1.005	Target gross inflation rate per quarter.
$\overline{u}^{\text{CB}}$	0.06	Target for unemployment rate.
$\overline{R}^{\text{CB}}$	1.015	Steady-state risk-free nominal interest rate per quarter.
ϕ_Π	1.500	Responsiveness of policy rate to inflation.
ϕ_u	0.158	Responsiveness of policy rate to unemployment.
ρ_D	0.700	Persistence of monetary policy shock.
$\sigma_D * 100$	0.103	Standard deviation of monetary policy shock
b	$0.435 * \overline{w}$	Unemployment insurance benefits per efficiency unit.
B	$0.265 * \overline{w}$	Leisure value per efficiency unit.

Notes: The table shows the calibrated parameters at the quarterly frequency. See the main text for explanations and details regarding calibration targets.

In particular, we use four discrete skill levels: $s \in S = \{s_1, s_2, s_3, s_4\}$. $\{s_1, s_2, s_3\}$ capture the productivity of "normal" households, with s_1 being 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 use the latter group of households in order to capture the skewed distribution of wealth in the U.S. economy; see Díaz-Giménez et al. (2011).

We parameterize the skill transitions by ensuring that in the steady state the model accounts for the following five targets: (i) 1 percent of the households are super-skilled; (ii) the Gini index of wealth is 0.82; (iii) the proportion of households that are borrowing-constrained is 0.10; (iv) the Gini index of earnings is 0.64; and (v) the autocorrelation of annual earnings of continuously employed workers is 0.9. The first target is motivated by the fact that the dynamics of individual earnings in the Panel Study of Income Dynamics (PSID) is reasonably replicated by an AR(1) process. We will use such a process for transitions between the normal skills. The PSID is known to under-sample the highest-income or highest-wealth households, which pins down the size of the super-skilled group. Targets (ii) to (iv) are calculated using the 2007 Survey of Consumer Finances. The last target (v) is motivated by existing empirical estimates of annual earnings persistence, most of which range between 0.9 and 1.[18]

This gives us five targets for the skill transitions. 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 by Adda and Cooper (2003). As regards transitions to or from the super-skilled state, we assume symmetry. Namely 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 each 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 6 reports the resulting transition probabilities per quarter. Figure 14 in Appendix D shows that the calibrated model closely matches the wealth distribution in the U.S. economy. In the same appendix, Table 18 shows that the model matches the main feature originating from this observation, namely, that "Wall Street" (the five percent wealth-richest households) derive a large share of income from financial wealth, whereas "Main Street" (the remaining 95 percent) does not.

[18] See for example the review in Nakajima (2012).

Table 6: Skill Transition Matrix

		future			
		s_1	s_2	s_3	s_4
today	s_1	0.9733	0.0260	0.0000	0.0007
	s_2	0.0260	0.9474	0.0260	0.0007
	s_3	0.0000	0.0260	0.9733	0.0007
	s_4	0.0223	0.0223	0.0223	0.9331

Notes: Transition probabilities per quarter, π_{s_i,s_j}, across skill groups. s_1 : lowest skill group, s_4 : highest skill group. Due to rounding, rows may not sum exactly to 1.

4.2 Capital-Producing Sector

The form of the capital adjustment costs is specified following van Binsbergen et al. (2012) as:[19]

$$\zeta\left(\frac{i}{K}\right) = \zeta_0\left(\frac{i}{K}\right)^{1-\zeta_1} + \zeta_2. \tag{38}$$

With regard to the parameters, we set the curvature parameter ζ_1 such that the volatility of hp-filtered log consumption (in the representative-agent version of the model with $\beta = 0.99$) is 0.77 as in the data. We target consumption volatility rather than investment volatility since the former is what is relevant for welfare. As is standard in the DSGE literature, the remaining parameters in equation (38) are pinned down by requiring that in the steady state adjustment costs do not affect behavior, so that $\zeta\left(\frac{i}{K}\right)K = i$ and $\zeta'\left(\frac{i}{K}\right)K = 1$. See the second block of rows in Table 5 for the corresponding values. The depreciation rate of capital follows the functional form specified by Greenwood et al. (1988), namely:

$$\delta(v) = \delta_0(v)^{\delta_1}. \tag{39}$$

We target a steady-state depreciation rate of $\delta_0 = 0.015$ (6 percent at annual rates) and choose a value of δ_1 such that the utilization rate is equal to 1 in the steady-state.

[19] The DSGE literature, following Christiano et al. (2005), typically entertains *investment* adjustment costs rather than *capital* adjustment costs. The former leads to a more drawn-out response of investment to shocks. The specification used here saves one state variable.

4.3 Intermediate Good Producer

Turning to the intermediate goods producers, we set the elasticity of substitution across intermediate goods to $\epsilon = 4$, implying a steady-state markup of 30 percent.[20] A low value for the elasticity makes sure that, numerically, we can entertain a Phillips curve with firmspecific price adjustment costs in the robustness section. It also makes the model numerically more stable toward a wider range of parameters of the monetary policy rule. 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 10. Parameter ψ governs the price adjustment cost. We set it to 57.12. 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. We set the reference level of inflation to $\overline{\Pi} = 1.005$ meaning there is complete indexation to a steady inflation rate of 2 percent per year. 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, $\rho_Z = 0.95$ is standard. The standard deviation of the TFP shock ($\sigma_Z = 0.005$) was calibrated such that GDP in the representative-agent version of the model (once H-P-filtered) has the same standard deviation as GDP in the data.

4.4 Labor Market

We match unemployment in our model to that underlying the unemployment rate "U6," that is, a concept that includes next to workers actively looking for work, both marginally attached and workers who work part time for economic reasons, following **?**. 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 10 percent, this results in a value of ;$\alpha = 1.677$. We time-aggregate Hall's monthly data to the quarterly frequency of our model such that the average duration of unemployment is the same in both Hall's data and the model. This suggests a quarterly average job-finding rate of 56%. We set a separation rate of $\lambda = 0.14$ per quarter so as to render this calibration in line line with a steady-state unemployment rate of 10%. 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 $\kappa = 0.166$. Any wage that leaves both firms and workers with a positive surplus from continuing the match will be an equilibrium wage. We postulate that the wage

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$$\log w(X) - \log \overline{w} = \epsilon_w \cdot \left[\log \left(\frac{GDP(X)}{N(X)} \right) - \log \left(\frac{\overline{GDP}}{\overline{N}} \right) \right], \tag{40}$$

thus being linked to labor productivity. Here $\overline{w}$ is the steady-state wage level. As before, $GDP(X)$ is defined as production $y(X)$ net of capital adjustment costs and fixed costs, both of which we see as intermediate inputs. $\epsilon_w \in [0, 1]$ represents the elasticity of the wage with respect to measured labor productivity. Values of $\epsilon_w < 1$ can be interpreted as reflecting "wage stickiness."[21] Following Hagedorn and Manovskii (2008), we target $\epsilon_w = 0.45$. We set the steady-state wage per efficiency unit of labor to $\overline{w} = 0.681$. This generates a labor share of 64 percent in GDP.

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exogenous separations. At the same time, unemployed workers have an acceptance probability of one, once matched with a firm. We have checked numerically that the wage always stays within the bargaining set. For the firm, we check that the value of the firm never becomes negative both in the simulation as well as for the policy function. For the worker, after tax wages never fall nearly enough to reach a 25 percent loss (the gap between the replacement rate and the wage in steady state), so employment is always preferred even over the business cycle. Since, throughout, we assume that wages and benefits are proportional to skills, that is enough to ensure that workers always want to work at the given wage.

4.5 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. Our model does not have mechanisms to explain the equity premium. The rate $\overline{R}^{\text{CB}}$ used in the Taylor rule is chosen with a target for the steady-state real rate of return of 4 percent in mind. The response of the policy rate to inflation in the Taylor rule is set at $\phi_{\Pi} = 1.5$. The response parameter to unemployment is set to $\phi_u = 0.158$. We determine this value to match the volatility of hp-filtered log unemployment in data and model (hp-weight 1,600). Using an *ad hoc* Okun's law with coefficient of 0.5, this choice for ϕ_u maps into roughly half the value of the original Taylor (1993)-rule coefficient on output. The target level for the unemploym $^{\text{CB}}$, is set to the steady-state level of unemployment (0.06). The New Keynesian literature often allows for "policy inertia" by having a lagged federal funds rate on the right-hand side of the Taylor rule. A typical value of the coefficient on the lagged interest rate is 0.7; for example, Clarida et al. (2000). Such a response would considerably complicate the computation since the lagged policy rate would be an aggregate state variable. In the current paper, instead, we opt for inducing the interest rate persistence through autocorrelation of the monetary policy shock, the persistence of which we set at $\rho_D = 0.7$. The standard deviation of the monetary policy shock, σ_D, is calibrated so that the model generates a volatility of hp-filtered log inflation rather close to the data. Absent monetary policy shocks, the model produces too little volatility in inflation and the nominal interest rate. The standard deviation of the monetary policy shock, σ_D, is calibrated so that the model generates a reasonable volatility of hp-filtered log inflation and the interest rate compared with the data, while still retaining a reasonable size for these shocks. We set $\sigma_D = 0.001$ so that a one-standard deviation monetary shock all else equal amounts to a 40 bps increase in the (annualized) nominal interest rate.

4.6 Government

With regard to the unemployment insurance system, we target a replacement rate (in the steady state) of 43.5 percent of earnings while setting the value of leisure to 26.5 percent. The total flow value of unemployment is 70 percent, which is close to the value argued for in Hall and Milgrom (2008). The value helps generate a realistic number of borrowing-constrained households without complicating the model by adding, for example, heterogeneity in discount factors or by choosing more extreme values for other parameters. 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 2.78 percent.

4.7 Business Cycle Statistics

This section reports how well the model matches the business cycle facts for the U.S. economy. The data are quarterly or quarterly averages of monthly data. Where applicable they are seasonally adjusted. Unless noted otherwise, their source is the St. Louis Fed's FRED II database. Nominal variables are deflated by the GDP deflator, which we also use for our measure of inflation, Π. Personal consumption expenditures, c, are from the national accounts. They include total durable and nondurable 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 U6 unemployment rate as our measure of $U(X)$. That measure is not available for our entire sample, but only from 1994. In order to have comparability, we use the unemployment rate (U3) to extrapolate earlier observations of the U6 rate, based on the comovement between the two from 1994 onward. 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 job-finding rate that results in the same duration of unemployment as the monthly job-finding rate in **?**'s data. Hall's data extend through September 2004. We extrapolate using the average of the monthly transition probability from unemployment to employment in the Current Population Survey (CPS). 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.

There is an ongoing discussion as to how the non-standard measures of monetary accommodation that the Federal Reserve implemented in the last recession have affected the economy and if and how they can be mapped into Taylor-type rules. We, therefore, want to steer clear of that episode and let our comparison sample end before the lower bound becomes binding. Accordingly, we focus on the period of the Great Moderation, from 1984Q1 to 2008Q3.

Table 8 compares second moments implied by the model and the data. In order to make data and model comparable, we report moments for the percentage deviation from trend for both the model-generated and actual time series. The trend was derived using the Hodrick-Prescott (H-P) filter with smoothing parameter 1,600 on the natural logarithm of the respective time series. The H-P filter was applied to the time series from 1984Q1 to 2008Q3. The model equivalent, equally, are derived by using 99 observations in the hp-filter.

Table 8: Model vs. data – second moments

	Model						Data		
	heterog. hh.			represent. hh.			1984Q1-2008Q3		
	Std	Corr	AR(1)	Std	Corr	AR(1)	Std	Corr	AR(1)
Output and components									
GDP (GDP)	1.35	1.00	0.67	1.32	1.00	0.67	1.37	1.00	0.90
Consumption (c)	0.86	0.99	0.72	0.74	0.99	0.72	0.77	0.86	0.82
Investment (i)	3.56	0.99	0.72	4.08	0.99	0.72	4.24	0.95	0.84
Capacity utilization (v)	0.55	0.82	0.34	0.51	0.79	0.32	1.86	0.77	0.89
Labor market									
Employment $N(X)$	0.52	0.94	0.68	0.51	0.94	0.68	0.88	0.81	0.93
Unemployment $U(X)$	8.63	-0.93	0.68	8.52	-0.92	0.69	7.95	-0.84	0.93
Vacancies (V)	6.99	0.74	0.10	6.83	0.74	0.11	10.27	0.90	0.92
Job finding rate (f)	4.22	0.90	0.41	4.10	0.90	0.41	6.07	0.75	0.81
Productivity and Prices									
$GDP(X)/N(X)$	0.88	0.98	0.67	0.86	0.98	0.66	0.95	0.89	0.84
Wage $W(X)$	0.40	0.98	0.67	0.39	0.98	0.66	0.92	0.42	0.83
Inflation Π [1]	0.64	-0.83	0.73	0.65	-0.85	0.73	0.67	0.32	0.26
Nominal rate R [1]	0.66	-0.95	0.77	0.69	-0.97	0.77	1.19	0.61	0.91

Notes: The table compares moments of the data and two variants of the model (heterogenous households, representative households). The model data are from 1,000,000 periods of simulations of the model. Each simulation is initialized with 500 periods of simulations that are dropped for the computation of the moments. In each case, we take the natural log of the data. Reported is 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. 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 autoregression coefficient. [1]: the nominal interest rate and inflation are reported in annualized percentage points. Some of the moments in the representative agent model where targeted based on 10,000 simulation runs. These targets are hit by the parameterization. The moments reported here may differ marginally from the target since the table shows moments for 1,000,000 runs.

The first three columns report second moments in the baseline model with heterogeneous agents. The second block of three columns reports the second moments of the representative-agent version of the model. These moments are included here for two reasons. First, as discussed above, we use the representative agent version 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 succeeds in replicating the main cyclical properties of GDP and its components, see the first four rows of Table 8. Consumption is less volatile than GDP and procyclical. Investment is considerably more volatile. Capacity utilization, too, is procyclical. It is less volatile in the model, however, than in the data. The heterogeneous households imply that aggregate consumption fluctuates more than under representative agents whereas investment fluctuates by less. The second block of rows in Table 8 compares business cycle properties of the labor market in the model and the data. The model succeeds in replicating the key cyclical properties of the labor market data: Unemployment and vacancies are both highly volatile. Unemployment is strongly countercyclical. The third block of Table 8 regards productivity and prices. The model matches the properties of labor productivity well, apart from implying - again – somewhat lower persistence. As in the data, the wage per employed household is less volatile than output.

The model economies are non-linear. Table 19 in Appendix F shows the mean of each variable (based on 1,000,000 simulation periods) and compares that to the non-stochastic steady state. In the baseline, the non-linearities are hardly visible in the means.

5 Transmission of TFP and Monetary Policy Shocks

We split the presentation of the results into two blocks. In the current section, we discuss the transmission of TFP and monetary policy shocks to the aggregate economy, the dependence of the transmission on the state of the economy, and how the shocks affect different segments of the population at different times. All of this will be conditional on the baseline calibration of the Taylor rule $\phi_\pi = 1.5$, $\phi_u = 0.158$. This serves as the basis for the discussion of the welfare results in Section 6.

We will discuss impulse responses that condition on two different initial states of the economy. We will label these states the "stochastic steady state" and the "deep recession state." The former is obtained as follows. We initialize the economy at the nonstochastic steady state. Then we simulate 500 periods of the stochastic economy assuming that in each period unexpectedly the innovations to the two shocks (monetary and TFP) are zero. This yields the state in period 500 that we label the "stochastic steady state." The "deep recession state" is obtained as follows. Starting at the stochastic steady state, we shock the economy by five periods of negative one-standard deviation innovations to the TFP shock and one-standard deviation contractionary monetary shocks. The resulting state, in period five is the "deep recession state."

5.1 Transmission of a Technology Shock

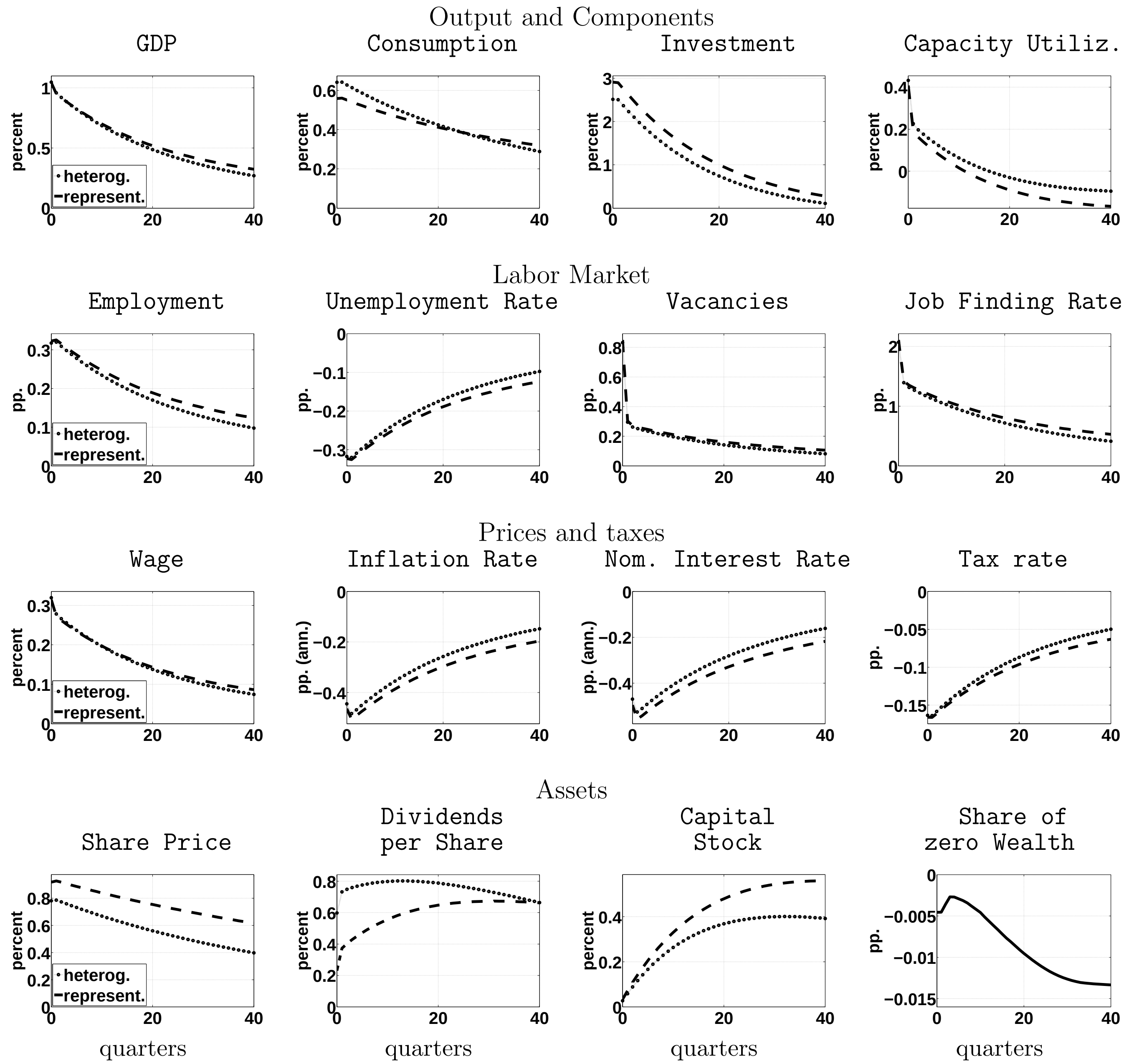
For comparison with the literature we start by discussing the transmission of a technology shock in the calibrated model economy.

5.1.1 Response of the Aggregate Economy to a Productivity Shock

Figure 2 shows the effect of a 1 standard deviation TFP shock on the aggregate economy starting from the nonstochastic steady state. The solid line shows the response in the baseline model (the model with heterogenous households). The dashed line shows the response in the model with a representative household, instead.

GDP rises by about one percent on impact. The household heterogeneity smoothes GDP somewhat compared to the representative agent economy. The composition of the increase in output, however, differs considerably from the representative-household case. In particular, consumption rises by more in the model economy with heterogeneous households. The reason is as follows. In response to the TFP shock, demand for labor services increases and so does the price of labor services. 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, by about 0.3 percentage point. The response of unemployment and 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). Rising employment and earnings translate into consumption by the high marginal-propensity-to-consume borrowing constrained households. The mirror image is that investment does not rise as much with heterogenous households as it would in a representative-agent world. This effect manifests itself over time. Ten years after the shock, the capital stock has risen by 0.1 percentage points less than in the representative-agent economy. Higher capital means a higher marginal product for labor services and, thus, a stronger response of employment in the representative-household economy. The economy with heterogenous households, instead, utilizes the existing capital stock more. As a result, marginal costs of production fall by less than in the representative-household economy, and so do inflation and the nominal interest rate. Note that wages respond in a very similar way in the two economies. The aggregate wage rises less than output by design; compare the wage

Figure 2: Response to a TFP Shock



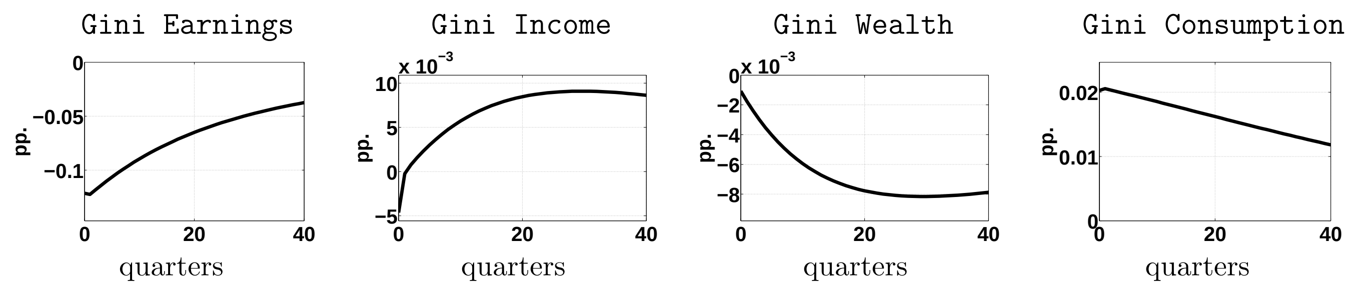
Notes: Impulse response to a 1 standard deviation TFP shock, Z. Solid line: the model economy with heterogenous households. Dashed line: same economy but with a representative household. For most of the variables, the y axis shows percent deviations from the no-shock path (y-label "percent"). "pp." refers to the deviation from the no-shock path in percentage points, "pp. ann" in annualized percentage points. The x-axis shows time since the shock in quarters.

equation (40).

5.1.2 The Effect of a Productivity Shock on Inequality

An important feature of the model is that a positive TFP shock raises the standard of living of all households rather uniformly. This is reflected in the impact of the TFP shock on the Gini indexes of earnings, income, wealth, and consumption, shown in Figure 3. The figures show the percentage point increase in the respective Gini index (a 100 pp. increase being a move from a Gini coefficient of zero to a Gini coefficient of 1). For the construction of the earnings Gini, the unemployed are counted as having zero earnings. Since the TFP shock has a positive effect on employment and thereby earnings, the earnings Gini drops by about 0.12 percentage points, that is from a Gini coefficient 0.64 to a Gini coefficient of 0.6388. The Gini coefficients for income, wealth, and consumption move, but by what seem to be very small amounts.

Figure 3: Response to a TFP Shock: Gini Indexes

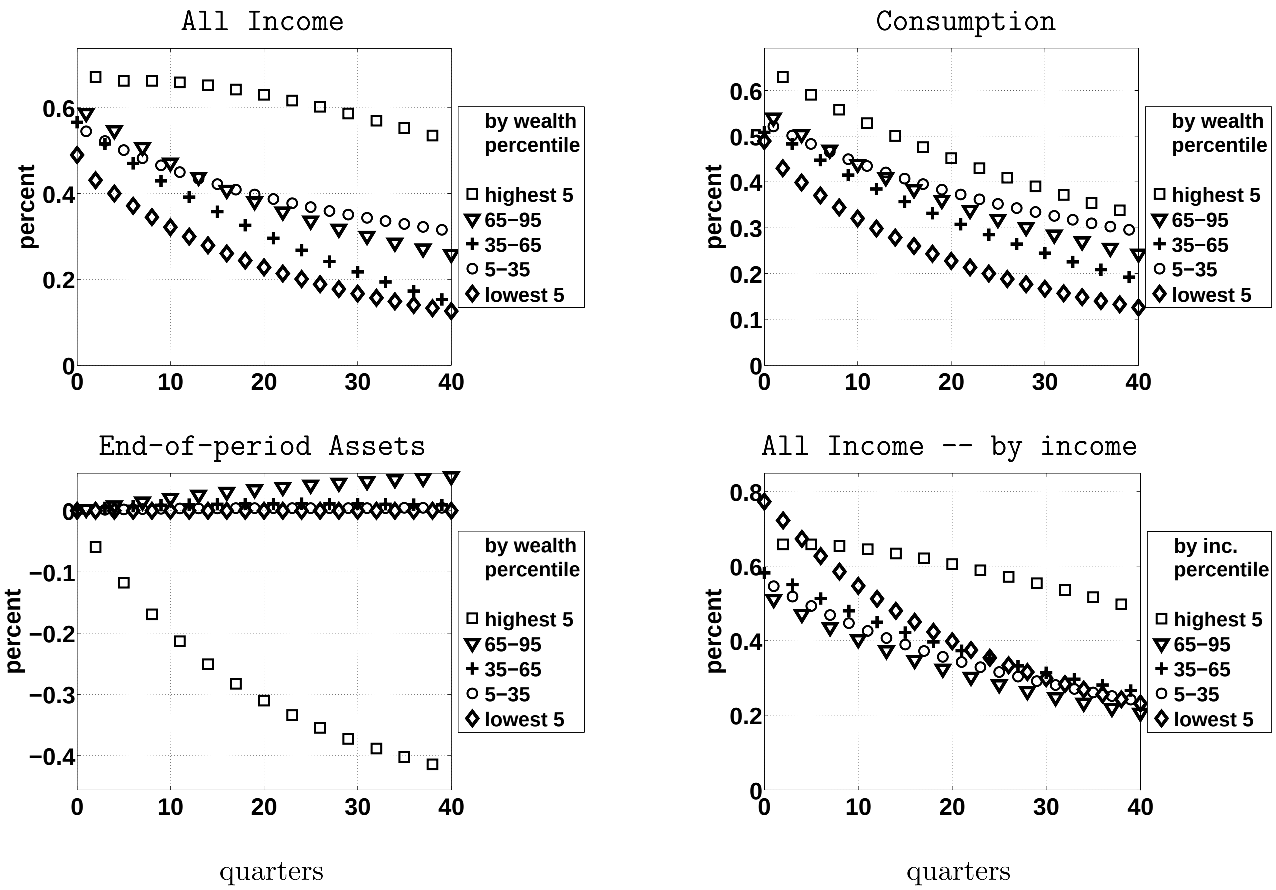


Notes: Impulse responses of Gini indexes of earnings (not conditioning on being employed), income, wealth, and consumption to a 1 standard deviation TFP shock. The figures show percentage point increases (an increase of "1" on the y-axis would increase the earnings Gini from, say, 0.64 to 0.65).

Figure 4 shows the responses of income, consumption, and asset-holdings for different percentiles of the wealth distribution (first three panels) or the income distribution (panel on lower right). Shown are the percentage responses when averaging along the respective dimension across different bins of the respective percentiles. For example, the diamonds in the first panel show the percentage increase in the average income of the bottom 5 percent of the wealth distribution (relative to no TFP shock materializing).[22] In response to a TFP shock, wages rise and employment increases. As a result, labor-related income rises for all segments of the population. The assumption of a common separation and job-finding rate, as well as a wage function that is common to all households, means that the labor earnings of all households are affected proportionally by the TFP shock. Wages do not respond one-to-one to labor labor productivity, however. Despite increased investment, dividends rise more than labor income, compare Figure 2. Capital holders' income thereby tends to rise by more in percentage terms than poorer

[22] The figures do not track the same households over time. Rather, households are assigned to the respective percentiles on the basis of their rank in the distribution of wealth at the end of each period.

Figure 4: TFP Shock: Individual Income, Consumption, and Share holdings



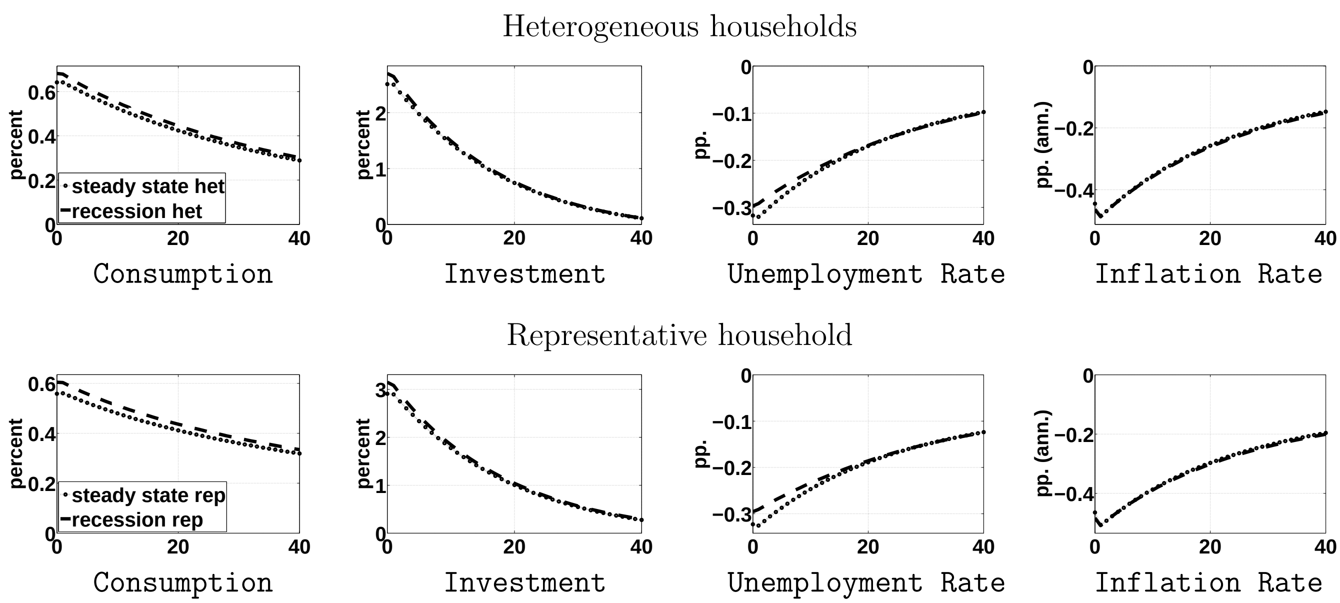
Notes: Impulse responses to a 1 standard deviation TFP shock. Shown are the responses of average income, consumption, or end-of-period asset holdings in the bottom fifth percentile ("lowest 5," diamonds), the 5th-35th percentile ("5-35," circles), 35th-65th percentile ("35-65," crosses), 65th-95th percentile ("65-95," triangles), and 95th-100th percentile ("highest 5" squares). Shown are repeated cross-sections. The percentiles refer to the distribution of beginning-of-period wealth for the first three panels. The panel on the bottom right plots the income response by the income distribution. All income includes all sources of income (after-tax earnings, transfers, and dividends).

household's income (left panel). Consumption rises the most for the wealth-richest segment of the population as well (squares in the panel on the first row on the right). The TFP shock leads to a narrowing of the wealth distribution; see panel on the bottom left. Households in the lowest wealth bin do not hold wealth. Since we show repeated cross-sections, this is so for all the quarters. The somewhat wealthier lower middle-class or middle-class households, however, use their rising labor income to increase asset holdings. By period 40 after the shock, the households around the 80th percentile of the wealth distribution (triangles "65-95") hold about 0.1 percent more shares (wealth). The very wealth-richest households, instead, after the TFP shock account for a smaller share of wealth in the economy. As the middle-class start saving, this increases asset prices and, thus, reduces *ex-ante* returns. This leads the wealth-richest to divest notably, namely about 0.45 percent of their share holdings.

5.1.3 TFP shocks in a deep recession

Next, Figure 5 analyzes the extent to which a TFP shock has different effects if it happens in a deep recession (dashed line) rather than in the stochastic steady state (circles). The first row shows the response of the model economy with heterogeneous households, the second row the economy with a representative agent. In both of the economies, in a deep recession, the responses of consumption and investment are somewhat stronger than at the stochastic steady state. The response of unemployment is somewhat weaker.

Figure 5: 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 heterogenous households. Second row: model economy with representative 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.

5.2 Transmission of a Monetary Policy Shock

Next, we analyze the effect of a contractionary one standard deviation monetary shock. For the purpose of the current paper, the main difference to the TFP shock will be the distributional implications.

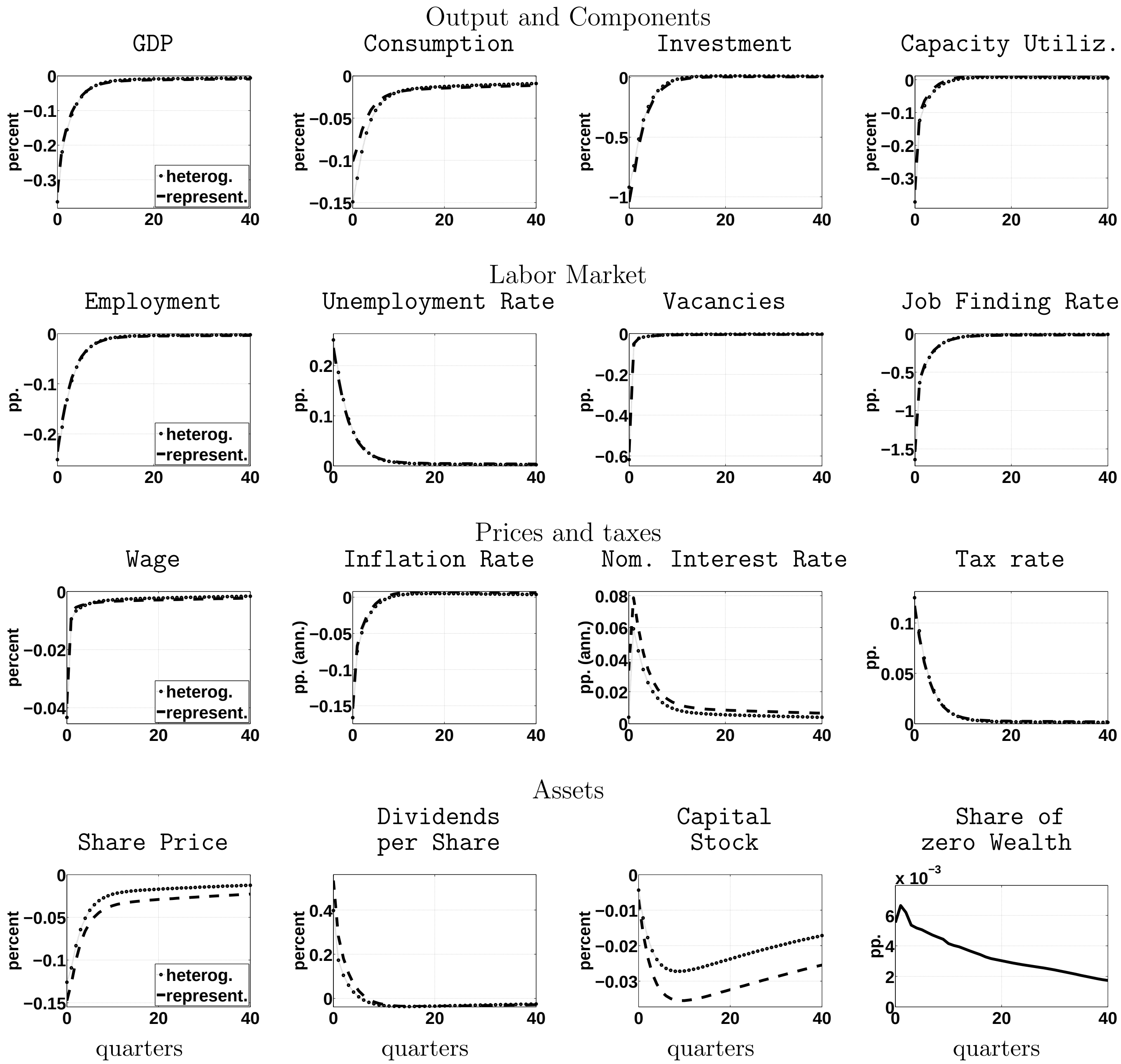
5.2.1 Response of the Aggregate Economy to a Monetary Policy Shock

By design, the monetary policy shock is persistent. It therefore raises the expected long-term real rate of interest. Higher expected returns lead households to save more and cut back their spending for consumption, namely by 0.1 percent (second panel in Figure 6). 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. At the same time, capacity utilization falls. GDP overall falls by 0.3 percent. Most of the responses are front-loaded. The reason is that in order to maintain a tractable size of the state space, our model does not include additional features that generate more drawn-out, hump-shaped responses; as, for example, mentioned in Christiano et al. (2005). A monetary policy tightening strongly affects the labor market (second row): On the one hand, the tightening reduces the demand for labor services and their price. On the other hand, such monetary policy raises the real rate of interest and therefore 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 1.5 percentage points). As employment falls, the unemployment rate rises by 0.25 percentage points (from a steady-state value of 6 percent to 6.25 percent). In the model with borrowing-constrained households, this increase in unemployment and idiosyncratic risk tends to further exacerbate the fall in consumption. However, it also ensures that investment and the share price do not fall as much as in the representative agent counterpart. The share of households who hold no wealth rises marginally. The reduced demand for production factors causes a reduction in capacity utilization and output per employed household. Consequently, the wage falls. With production factors in lower demand, the rental rates for both labor and capital services fall. Since marginal costs fall, inflation falls as well, namely, by 0.15 percentage point (annualized). By the logic of the Taylor rule, equation (21), a positive monetary shock leads to a persistent increase in the *ex ante* long-term real rate of interest. In the simulations shown here, the increase in the long-term real rate of interest reduces inflation and unemployment in a front-loaded manner. The nominal rate, therefore, rises by less than 40 basis points (ann.). What matters for the contractionary effect of monetary policy is that the central bank commits to keeping the real rate of interest higher than usual.

The final row of Figure 6 shows the response of asset-related variables to the monetary policy shock. As the discount rate rises and investment becomes less profitable, the mutual funds pay out "excess" cash-flow through dividends.[23] In the medium term, however, dividends fall as the

[23] The current paper does not allow firms to retain earnings. However, apart from accounting, this should not have a large effect on our results regarding consumption inequality and welfare. The timing of dividends matters primarily for households that are at the borrowing constraint. These households, however, do not

Figure 6: Response to a one-standard deviation monetary shock



Notes: Impulse response to a one-standard deviation monetary policy shock, D. Solid line: the model economy with heterogenous 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, "pp. ann" in annualized percentage points. The x-axis shows time since the shock in quarters.

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hold shares in the first place. All other households can undo dividend payments that they consider ill-timed by adjusting the number of shares thev hold. The data bear out this increase in financial income and dividends upon a monetary shocks.

below-average investment in both labor and capital drains the productive resources available to firms.[24]

While dividends rise, this does not imply that the same is due for profits. The model has two different sources of *ex-post* profits. The left panel of Figure 7 shows that profits in the intermediate goods (sticky-price) sector rise with tighter monetary policy. The reason is that a monetary contraction reduces marginal costs. Due to sticky prices, then, markups in the sticky-price sector increase. This alone would suggest that wealthier households stand to benefit from contractionary monetary policy. However, this argument neglects that capital and labor services firms can make profits and or losses *ex post* as well. And since both employment and capital are investment goods in our model, the losses upon a monetary contraction can be steep because both the rental rate of capital $r(X)$ and the rental rate for labor services $h(X)$ fall (not shown in Figure 6). On balance, the profits of all these three firms combined *fall* after a contractionary monetary policy shock, and a little more so than GDP; compare the right panel of Figure 7.

Figure 7: Profits

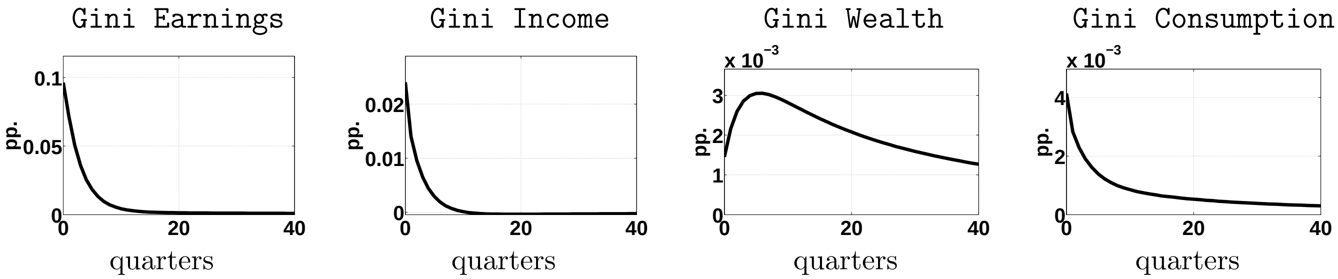
Notes: Same as Figure 6. Shown is the response of profits in the intermediate goods sector (left panel). And profits in the overall economy (before physical investment and vacancy posting costs).

5.2.2 The Effect of a Monetary Shock on Inequality

Figure 8 shows the responses of the Gini indexes for earnings, income, wealth, and consumption. The monetary policy shock has a smaller effect on output than the TFP shock, but a comparable impact (in terms of absolute size) on unemployment. Thus, when monetary policy tightens unexpectedly, the earnings Gini rises, by 0.1 percentage point. This is due to the incidence of higher unemployment, which means that fewer households earn labor income. The Gini indexes of both wealth and consumption increase persistently. The order of magnitude of those increases is similar to that for a one percent TFP shock.

[24] Christiano et al. (2005) find that profits fall in response to a contractionary monetary policy shock. This does not contradict our results. In their paper, profits entail only the profits made in the Calvo sector and not the cash-flow generated by capital production (which they specify as accruing in the household sector).

Figure 8: Response to one standard-deviation monetary 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).

Figure 9 shows the response of income, consumption, and asset-holdings for different percentiles of the wealth and income distribution. Focus, first, on the left-most panel in the first row. Upon a monetary policy shock, both employment and wages fall. Incomes thereby fall across the wealth distribution with the exception of the wealth-richest 5 percent. For the latter group, income (as measured in the model) initially increases on the back of higher dividends. In the model, monetary policy, therefore, has distributional effects on incomes. A similar picture emerges when cutting the response by the income percentile. The monetary shock leads households to substitute consumption intertemporally. In addition, it raises earnings risk. All households thereby scale back their consumption (first row, panel on the right). Only the very wealth-richest, however, increase savings, that is, accumulate additional assets. The remaining households, instead, dissave.

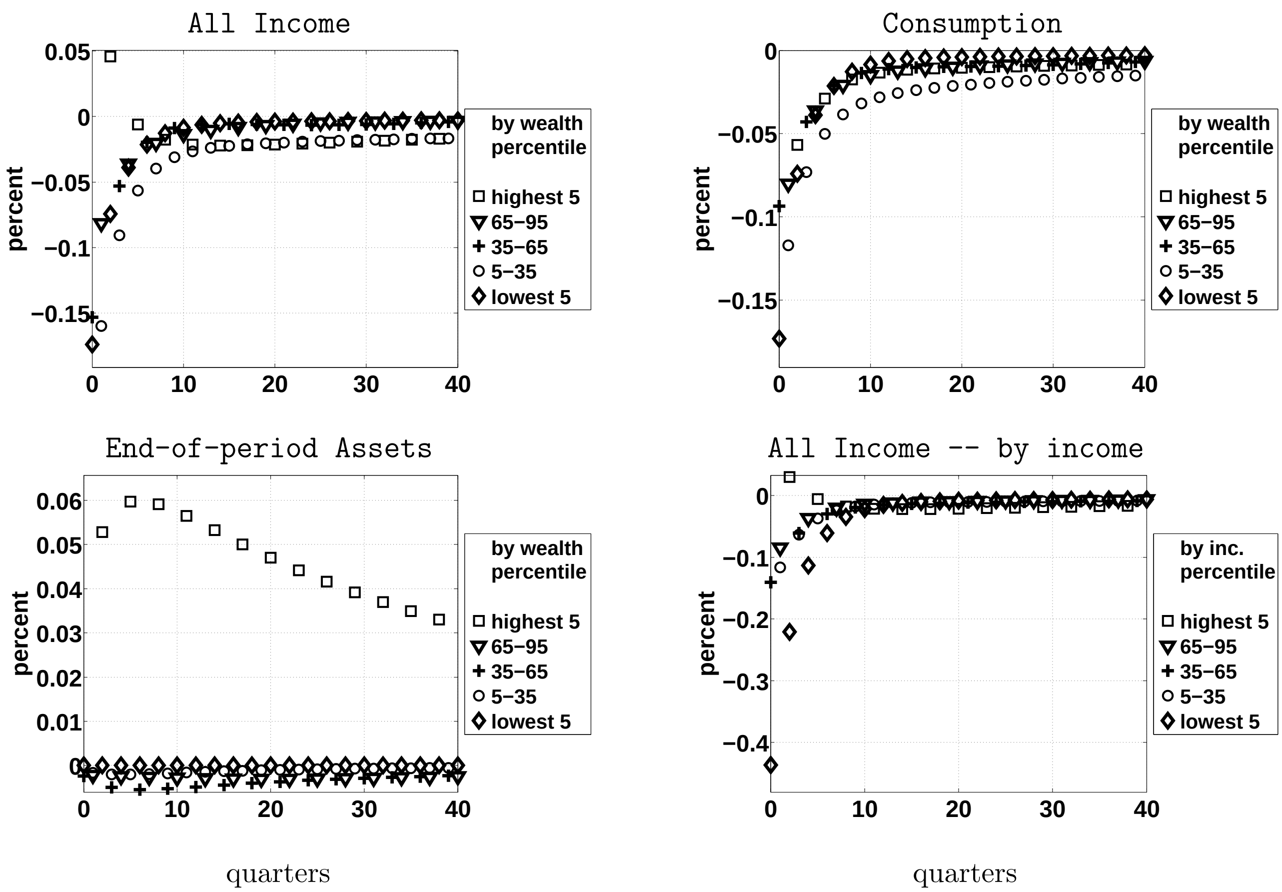
5.2.3 Monetary shocks in a deep recession

Next, Figure 10 analyzes the extent to which the impulse responses to a contractionary monetary shocks are state dependent. The exercise is the same as that underlying Figure 5, apart from now looking at a monetary shock in a deep recession. Similar to the results that we had for the TFP shock, the effects of the shocks are state-dependent. Monetary shocks are more contractionary in a recession. As before, however, the heterogeneity of households appears to mitigate the state-dependence, which is considerably more visible in the representative-agent model variant.

6 Heterogeneous Welfare Effects of Monetary Policy

In this section, we explore the welfare implications of both the shocks and the choice of the systematic component of monetary policy, using the heterogeneous-agent model that we developed. In Section 6.1 we study the short-run welfare effects of a TFP and a monetary policy shock.

Figure 9: Monetary shock: Individual Income, Consumption, and Share holdings



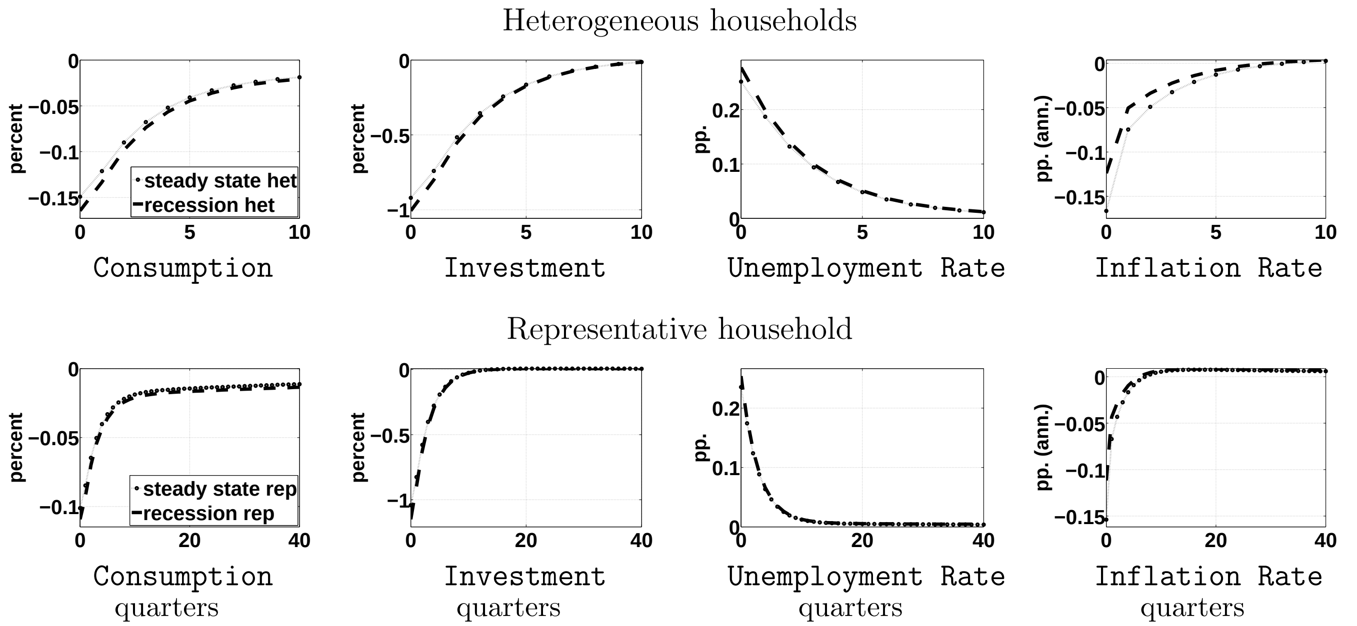
Notes: Impulse responses to a one standard-deviation monetary shock. Shown are the responses of average income, consumption, or end-of-period asset holdings in the bottom fifth percentile ("lowest 5," diamonds), the 5th-35th percentile ("5-35," circles), 35th-65th percentile ("35-65," crosses), 65th-95th percentile ("65-95," triangles), and 95th-100th percentile ("highest 5" squares). Shown are repeated cross-sections. The percentiles refer to the distribution of beginning-of-period wealth for the first three panels. The panel on the bottom right plots the income response by the income distribution. All income includes all sources of income (after-tax earnings, transfers, and dividends). For better readability, the figure does not plot every observation.

In Section 6.2 we explore the importance of the systematic response of monetary policy to economic activity. First, we focus the welfare costs of a recessionary TFP shock when there are differently-sized monetary responses to unemployment. We evaluate the welfare costs relative to the respective stochastic steady state. In Section 6.3, then, we discuss the distributional effects when taking account of the transition path to a more accommodative monetary policy.

6.1 Short-Run Welfare Effects of Productivity and Monetary Policy Shocks

What are the short-run welfare effects of a TFP and a monetary policy shock in the baseline calibration? Table 9 summarizes the welfare effects of the two shocks if the economy initially is

Figure 10: Effect of state of the economy on IRFs to a monetary Shock



Notes: Impulse response to a 1 standard deviation monetary policy shock, D. 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.

in the stochastic steady state. The welfare gains or costs are measured as consumption equivalents. For example, an entry of "-1" would mean that a household would be willing to forgo 1 percent of consumption in *every* period and state in the future in order not to live through the shock episode. Focus, first, on the column titled "TFP Shock." The first row ("RA") shows the consumption equivalent when, counterfactually, computing welfare and the consumption equivalent using aggregate consumption and the CRRA utility function. By this measure, a one-time one standard-deviation TFP shock raises aggregate welfare by about 0.24 percent of life-time consumption. The second row ("HA") averages over the consumption equivalents of each household in the heterogeneous agents world. Under this measure, society on average values the TFP shock at 0.31 percent of life-time consumption. The difference between the RA and HA measures suggests tracing the welfare effects more finely according to the wealth distribution. All wealth-classes benefit from the expansion generated by the TFP shock: A positive TFP shock "lifts all the boats." However, the table also indicates that the welfare gain from a positive TFP shock is strongest for the Wall Street (wealth-rich households). This is so because wage rigidity imparts more of the TFP gains to capital owners than to workers.

A monetary policy shock (column "MP Shock" of the same table) implies similarly uniform

Table 9: **Welfare Effects of Monetary Policy and TFP Shocks**

	TFP Shock	MP Shock
Social Welfare		
Representative Agent (RA)	0.24	–0.013
Average of all Households (HA)	0.31	–0.020
By Wealth Holdings		
Top 5 percent	0.46	–0.015
5–20 percent	0.36	–0.017
20-40 percent	0.31	–0.018
40-60 percent	0.30	–0.019
60-80 percent	0.28	–0.021
80-95 percent	0.27	–0.026
Bottom 5 percent	0.27	–0.026

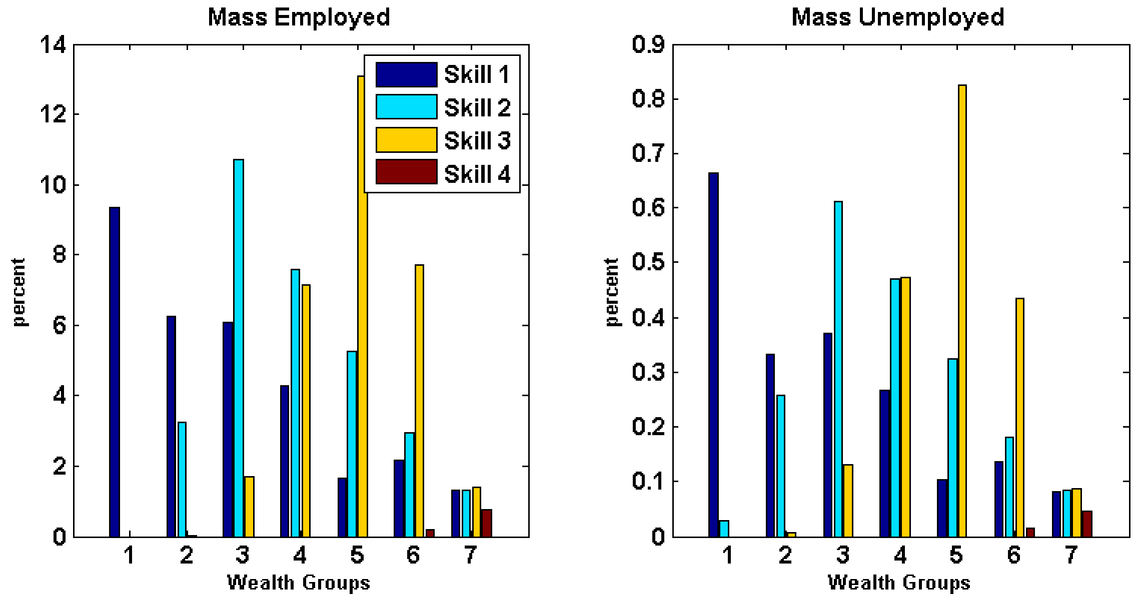
Notes: The table shows the welfare gains of a one-time one-standard deviation positive TFP shock and a one-standard deviation contractionary monetary policy shock. Welfare is measured by the percentage increase in life-time consumption, compared with the initial condition. The first two rows show welfare costs based on aggregate consumption and CRRA utility ("RA") and based on a utilitarian concept, giving all households the same weight ("HA"). Underneath "By Wealth Holdings," the table reports the consumption-equivalent welfare gains and losses for different households, when sorting these according to their wealth.

effects. The ordering of welfare losses is different, however. Here, the 5 percent richest households in terms of wealth holding lose *least* from the monetary tightening (and would gain least from a monetary easing). For this class, in consumption-equivalent terms the loss from a one-time tightening class amounts to 0.015 percent of life-time consumption. The wealth-poorest instead lose about twice as much (0.026 percent).

Of course, the effects above may mask considerable heterogeneity within wealth groups. For the stochastic steady state, Figure 11 shows the distribution of households across individual household's states. Labor income and wealth are positively correlated. Of the ten percent no-wealth households, all but a tiny fraction are of the lowest skill level. Similarly, the highest wealth groups tend to disproportionately contain higher-skilled workers. Comparing the left and the right panel, unemployed workers will transit to a lower level of wealth. As a result, for the unemployed, the correlation between skill and wealth is not as pronounced as for the employed.

Zooming in by an individual household's states, we find that by and large the TFP shock affect all households rather uniformly, see Table 20 in Appendix F. This contrasts starkly with

Figure 11: Mass of households by individual state



Notes: The plots show the distribution of the mass of households by employment status, skill and wealth in the stochastic steady state. Wealth group 1 contains all households with zero assets, Wealth group 2 the next 10 percent in terms of wealth, group 3 the 20-40 percent, group 4 the 40-60 percent, group 5 the 60-80 percent, group 6 the 80-95 percent and group 7 the top 5 percent by wealth. The respective cutoffs for the bins are wealth levels of 0, 0.02, 0.12, 0.33, 0.61, and 4.71 times the average wealth holdings in the economy.

the distributional consequences of a monetary shock, for which Table 10 presents the distributional break-down by individual states. There is up to a ten-fold difference in the welfare costs for different households. Two groups are loosing most after a contractionary monetary shock:

Table 10: Welfare effects of a monetary shock by skill, employment, and wealth

Wealth	skill (low to high), employed			
level	s_1	s_2	s_3	s_4
Top 5%	–0.013	–0.013	–0.014	–0.027
Median	–0.016	–0.017	–0.019	–0.039
Zero wealth	–0.025	–0.022	–0.022	–0.041
Wealth	**skill (low to high), unemployed**			
level	s_1	s_2	s_3	s_4
Top 5%	–0.014	–0.015	–0.019	–0.077
Median	–0.021	–0.028	–0.038	–0.134
Zero wealth	–0.053	–0.046	–0.048	–0.144

Notes: The table shows the welfare gains of a one standard deviation positive (contractionary) monetary policy shock for selected wealth levels. See the notes to Table 20 for detailed notes.

households with zero wealth and households with the highest skill levels, particularly so if they are unemployed. The former do not have a means of smoothing consumption in the wake of a recession. The latter households face a higher risk of an extended unemployment spell at a time when they are, temporarily, most productive.

6.2 Welfare and the Systematic Response to a Recession

So far we have focused exclusively on the role of shocks for a given "baseline" monetary policy. In the remainder of the paper, we will investigate the welfare effects of having a systematically more accommodative monetary policy. We focus, in this section, on the long-run, that is, compare the effect of shocks on welfare for permanently different policy rules. This lays the ground for the next section, which will take into account the transition to the different policy rule.

Table 11 shows the welfare costs of a one-time one-standard deviation negative TFP shock.[25] for permanently different monetary policies. The left-most columns has monetary policy react less

Table 11: TFP and Accommodative Monetary Policy

	$\phi_u = 0.05$	Baseline	$\phi_u = 0.25$	$\phi_u = 0.50$
Social Welfare				
Average of all Households (HA)	–0.3572	–0.3124	–0.2893	–0.2505
By Wealth Holdings				
Top 5 percent	–0.5031	–0.4690	–0.4492	–0.4080
5–20 percent	–0.4032	–0.3640	–0.3430	–0.3045
20-40 percent	–0.3601	–0.3179	–0.2959	–0.2583
40-60 percent	–0.3471	–0.3035	–0.2811	–0.2433
60-80 percent	–0.3267	–0.2797	–0.2559	–0.2177
80-95 percent	–0.3241	–0.2709	–0.2443	–0.2034
Bottom 5 percent	–0.3238	–0.2697	–0.2427	–0.2013

Notes: The table shows the welfare gains (positive) and welfare costs (negative) of a one standard deviation negative TFP shock. Welfare is measured by the percentage increase in life-time consumption, compared with the initial condition. The first two rows show welfare costs based on aggregate consumption and CRRA utility ("RA") and based on a utilitarian concept, giving all households the same weight ("HA"). Underneath "By Wealth Holdings," the table reports the consumption-equivalent welfare gains and losses for different households, when sorting these according to their wealth.

to unemployment than in the baseline ($\phi_u = 0.05$ instead of $\phi_u = 0.158$), the right-most column

[25] This is a shock with the opposite sign of that shown in Table 9.

more ($\phi_u = 0.5$ instead of $\phi_u = 0.158$). Society as whole would prefer a more accommodative monetary policy (a stronger response to unemployment in the policy rule). The shock has uniformly lower welfare costs under the latter policy than in the baseline. We will show next, however, that this comparison of shocks hitting the economy in different stochastic steady states is misleading.

6.3 Implications of Transition to more Accommodative Monetary Policy

The results in the previous section suggest that households, regardless, of skill level and wealth might benefit more accommodative monetary policy than was embedded in the baseline. The previous results, however, compared fluctuations around different stochastic steady states. Table 12, instead, takes the transition path into account. Namely, the table documents the welfare

Table 12: Welfare effect of permanent policy change

	$\phi_u = 0.05$	$\phi_u = 0.25$	$\phi_u = 0.5$
Social Welfare			
Representative Agent(RA)	–0.1002	0.0255	0.0223
Average of all Households (HA)	-0.0707	0.0186	0.0404
By Wealth Holdings			
Top 5 percent	–0.062	–0.016	–0.14
5-20 percent	–0.068	0.006	–0.03
20-40 percent	–0.071	0.016	0.02
40-60 percent	–0.072	0.020	0.04
60-80 percent	–0.073	0.026	0.09
80-95 percent	–0.072	0.031	0.12
Bottom 5 percent	–0.071	0.031	0.08

Notes: Welfare effects in response to a permanent policy change from the baseline calibration to $\phi_u = 0.05$, $\phi_u = 0.25$, or $\phi_u = 0.5$. The numbers take into account the transition from the initial stochastic steady state (under $\phi_u = 0.158$) to the new stochastic steady state. Welfare is measured by the percentage increase in life-time consumption, compared with the initial equilibrium. The first two rows show welfare costs based on aggregate consumption and CRRA utility ("RA") and based on a utilitarian concept, giving all households the same weight ("HA").

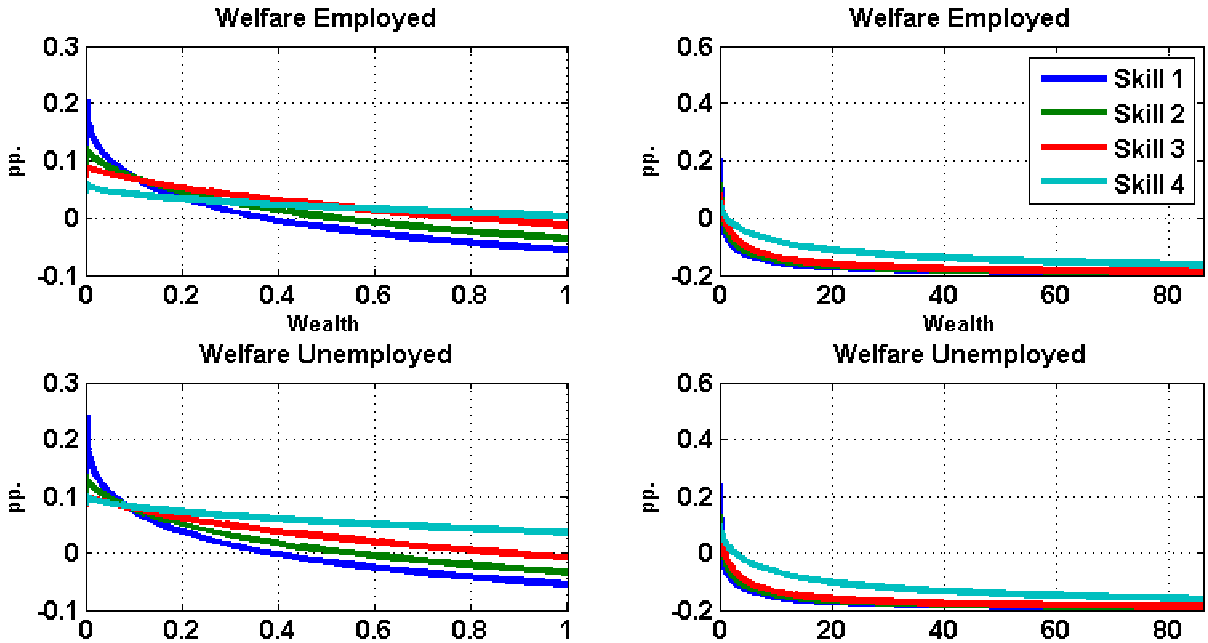
gains of moving toward systematically more hawkish monetary policy (a smaller response to unemployment, left-most column) or more accommodative monetary policy (center and right-most column), starting at the stochastic steady state associated with the baseline response of the nominal rate to unemployment (the baseline had parameter $\phi_u = 0.158$). Uniformly (in the wealth dimension) households dislike transiting to a monetary policy that focuses more on inflation, and thereby imparts more fluctuation in aggregate unemployment. The welfare loss of moving to such a policy is about 0.07 percentage points. The reason is that, on the transition path, households would build up savings for precautionary reasons, which – in the short-term – hurts their consumption. In addition they would be subject to a more volatile economy.

There is considerably stronger disagreement among the wealth classes, however, with regard to moving toward a more *accommodative* policy than in the baseline. Toward this end, focus on the right-most column of the above Table 12. That column features a response coefficient to unemployment that is about four times as large as in the baseline. While the wealth-poorest gain about a tenth of a percentage point of life-time consumption from a transition to a more accommodative monetary policy, the average wealth-rich household *looses* from such a change, and significantly so. The great majority of society, however, would favor a change to consistently more accommodative monetary policy.

More accommodative monetary policy puts more emphasize on stabilizing economic activity and, thus, reduces income risk. Indeed, in the long run, under such a policy the standard deviation of GDP falls by 20 percent (case $\phi_u = 0.5$). The standard deviations of employment and wages fall by about 40 percent, compare Table 21 in Appendix F. In spite of the ensuing fall in (precautionary) savings, GDP and employment rise (by about 0.2 percentage points). This is in line with the non-linearities in the search and matching model documented by Hairault et al. (2010) and Jung and Kuester (2011), by which less volatile economic activity translates into lower unemployment on average. This comes at the expense of higher inflation volatility. The standard deviation of inflation rises by two thirds.

Figure 12 explains the welfare effects in greater detail for one case, namely, for the switch to $\phi_u = 0.5$. The figure shows the welfare gains from the switch (relative to the baseline) by employment status (rows), skill level (different lines), and wealth (x-axis). The left column has a range of wealth on the x-axis that covers 2/3 of the households. The column on the right, covers the whole range of wealth. A larger reaction coefficient ϕ_u means that monetary policy reduces the income risk in the economy. Households, therefore, reduce their current or future precautionary savings and nevertheless face smoother consumption streams. This benefits, in particular, those households who have a high marginal propensity to consume and fewer assets, particularly so if low-skilled and unemployed. The gain from more accommodative policy for a household that has no assets, is unemployed, and has the lowest skill level amounts to about a quarter percent of life-time consumption. Skills are not a sufficient statistic for assessing winners and losers from monetary accommodation. Neither is wealth alone. In particular, it is the

Figure 12: Welfare Gains of Switching from Baseline to $\phi_u = 0.5$



Notes: This figure shows the welfare changes from a switch from the baseline monetary policy rule to one with $\phi_u = 0.5$ by the households' individual states. First row: conditional on being employed. Second row: conditional on being unemployed. In each of the panels, the four lines refer to the skill level (ordered from lowest to highest). Shown is the welfare gain in terms of a percentage change of households lifetime consumption (y-axis) for different wealth levels (x-axis). The only difference between the panels in the left column and those in the right is the range shown on the x-axis. In the left column, the range goes from 0 to one, covering about 2/3 of the households. The panels on the right show all asset levels.

wealth-rich but income-poor who lose most from a switch to accommodative policy. This class of agents has build up savings at a time when they were higher-skilled, but seeks to dissave now. They dislike the change to accommodative policy because the change reduces demand for precautionary savings, which in turn reduces the share price of the mutual funds during the transition phase. At the same time, given their current skill level and relative to their wealth, they have little to gain from higher employment; the right-most column of Figure 12 highlights this. Figure 17 in Appendix F shows the welfare gains directly by wealth percentile (having the latter on the x-axis). For completeness, Figures 15 and 16 in Appendix F provide the graphs for the switch to $\phi_u = 0.25$ as well.

Summarizing, agents in our model economy are similar in many respects: they save through mutual funds and, thereby, have the same portfolio composition. In equilibrium, households' portfolios do not contain nominal assets at all. Nevertheless, monetary policy options are conceived very differently by different segments of the population. Wealth alone is not a sufficient statistic for a households' attitudes toward accommodative policy. Households that have low wealth relative to their potential labor income favor the change to accommodative policy. Households for which wealth is high relative to labor income, instead, would rather prefer not to switch to more accommodative policy. There are few of those households, however, Overall, then a majority of households favor a switch to more accommodative policy: 91 percent of households would favor to move from our baseline to a response with $\phi_u = 0.25$ (roughly Taylor's 1993 rule), 84 percent of households would prefer to go to $\phi_u = 0.5$ (roughly Taylor's 1999 rule).

7 Robustness

The previous section suggested that a transition to a more accommodative monetary policy benefits wealth-poor households at the expense of those households who are (relative to their labor income) wealth rich. A great majority of agents in the baseline model favors a transition to more accommodative monetary policy. This raises the question why monetary policy is not more accommodative in the first place, which leads us to assess the robustness of our results along several dimensions.

7.1 Markup shocks

One candidate explanation might be that the set of shocks that we looked at is limited. For example, a pure "cost-push shock" might be considered important for two reasons. On the one hand for comparison. The existing literature with heterogenous households, but flexible prices, is often concerned with events in which there is surprise inflation. It may, therefore, be useful to have such shocks. On the other hand, such cost-push shocks provide a genuine policy trade-off. In sensitivity analysis, we have thus modeled these shocks, namely, as shocks to the price markup (the elasticity of substitution between goods). We replaced the monetary shock by the markup shock and recalibrated the model to match the same four moments as before (which include the standard deviation of inflation). The results above proved robust to introducing such inefficient shocks.

7.2 Output-specific price-setting costs

Another candidate explanation is the following. A central bank that responds more to unemployment tolerates that, at the same time, inflation volatility increases. Higher inflation volatility in turn, may cause higher average markups. In order to explore this channel quantitatively, we model the price-adjustment costs as being partially firm-specific by assuming that a fraction of them multiplies demand. Under this specification, the Bellman equation of the sticky-price firm changes from equation (6) to

$$
\begin{aligned}
J_I(X_p) = \max_{P_j,\ell_j,k_j} y_j(X,P,P_j)\left(\frac{P_j}{P(X_p)}\right) &- r(X)k_j - h(X)\ell_j \\
&- \frac{\psi}{2}\left(\frac{P_j}{P_{j,-1}} - \overline{\Pi}\right)^2 (\gamma y_j(X,P,P_j) + (1-\gamma)\bar{y}) \\
&- \Xi + \mathbb{E}\left[Q(X,X')J_I(X',P_j)\right] \\
\text{s.t.} \qquad y_j(X,P_j,P) &= \left(\frac{P_j(X_p)}{P(X_p)}\right)^{-\epsilon} y(X), \\
y_j(X,P_j,P) &= Z k_j^{\theta} \ell_j^{1-\theta},
\end{aligned}
$$

The difference to the baseline specification is in the second line. Parameter $\gamma \in [0,1]$ indexes the extent to which price adjustment costs depend on activity at the firm level. Previously, we have assessed the case $\gamma = 0$, so that the price adjustment costs did not depend on the firm's output level. Other papers, for example, Fernández-Villaverde et al. (2011) use the case $\gamma = 1$. In the current section we will assume that $\gamma = 0.75$. This is consistent with evidence that a large share of price-setting costs arise at the own firm in the form of either managerial costs or time that staff spend communicating price changes to customers; see, for example, Zbaracki et al. (2004). Up to first order, the change leaves the Phillips curve identical to the one examined in the main text, irrespective of the value of γ. Instead, the difference will show in higher-order terms. The new term increases the average markup if inflation is volatile. The reason is as follows. With output-specific price-setting costs, correcting (that is, raising) too low a price (at which there, consequently, is more demand for the good) is more costly than correcting (that is, reducing) too high a price (at which demand is low). One can show this analytically for special cases, see Appendix B for such an example.

Table 13 shows the welfare gains of different wealth groups (positive numbers; negative numbers are and welfare losses) from moving to a more accommodative policy, again from $\phi_u = 0.158$ to $\phi_u = 0.25$. The only change to the results shown earlier is the form of the Phillips curve, otherwise the rest of the model and calibration remained unchanged. The five percent wealthiest households lose about the same amount as they did absent output-specific costs of price adjustment. What is more important is that now the wealth-poor also lose from accommodative policy. The reasons are as follows. More accommodative policy raises inflation variability, which in turn raises markups. As a result, the economy no longer witnesses the gains in output and employment shown in Table 21. Second, with firm-specific price adjustment costs, the accommodative

Table 13: Welfare implications of transition to more accommodative policy ($\phi_u = 0.25$) under output-specific pricing costs

	$\phi_u = 0.25$	$\phi_u = 0.25$ (Deep Recession)
Social Welfare		
Average of all Households (HA)	–0.0876	–0.0578
By Wealth Holdings		
Top 5 percent	–0.1540	–0.1996
5-20 percent	–0.1097	–0.1110
20-40 percent	–0.0928	–0.0728
40-60 percent	–0.0848	–0.0565
60-80 percent	–0.0737	–0.0285
80-95 percent	–0.0663	0.0009
Bottom 5 percent	–0.0643	–0.0054

Notes: Same as Table 12 but for the fact that the intermediate goods firms now have output-specific price-adjustment costs.

policy is less successful in stabilizing employment; see Table 22 in the Appendix. With the parameter change, the variability of employment falls by 15 percent rather than by 17 percent. At the same time, the standard deviation of inflation rises by 26 percent as opposed to an increase of 22 percent.

Figure 13 shows the welfare gains by individual state. Compared to Figure 12, it shows an important element of the welfare effects. Namely, the welfare losses from the accommodative policy continue to rise in the wealth of the individual household.

7.3 Long-term unemployment

Next, we have extended the model along several different dimensions. First, we have include a state of long-term unemployment (with a very low replacement rate). This increases the costs of business cycles and the scope for distributional effects of monetary stabilization policy. **RESULTS TO BE ADDED**.

Table 14: Long Term Unemployment Model – second moments

	Model					
	hp-filtered			unfiltered		
	Std	Corr	AR(1)	Std	Corr	AR(1)
Output and components						
GDP (GDP)	1.37	1.00	0.69	4.07	1.00	0.96
Consumption (c)	0.87	0.99	0.73	3.48	0.98	0.98
Investment (i)	3.72	0.99	0.74	8.24	0.87	0.94
Capacity utilization (v)	0.60	0.83	0.37	1.22	-0.01	0.85
Labor market						
Employment $N(X)$	0.53	0.96	0.73	1.59	0.99	0.97
Unemployment $U(X)$	8.50	-0.86	0.43	16.95	-0.93	0.85
Long Term Unemployment $LU(X)$	10.32	-0.80	0.88	34.08	-0.95	0.99
Job finding rate (f)	3.12	0.85	0.31	6.02	0.94	0.81
Long Term Job finding rate (lf)	7.29	0.84	0.32	14.08	0.94	0.81
Productivity and Prices						
$GDP(X)/N(X)$	0.88	0.98	0.65	2.50	0.99	0.96
Wage $W(X)$	0.39	0.98	0.65	1.13	0.99	0.96
Inflation Π [1]	0.62	-0.89	0.76	2.05	-0.98	0.98
Nominal rate R [1]	0.64	-0.96	0.79	2.16	-0.99	0.98

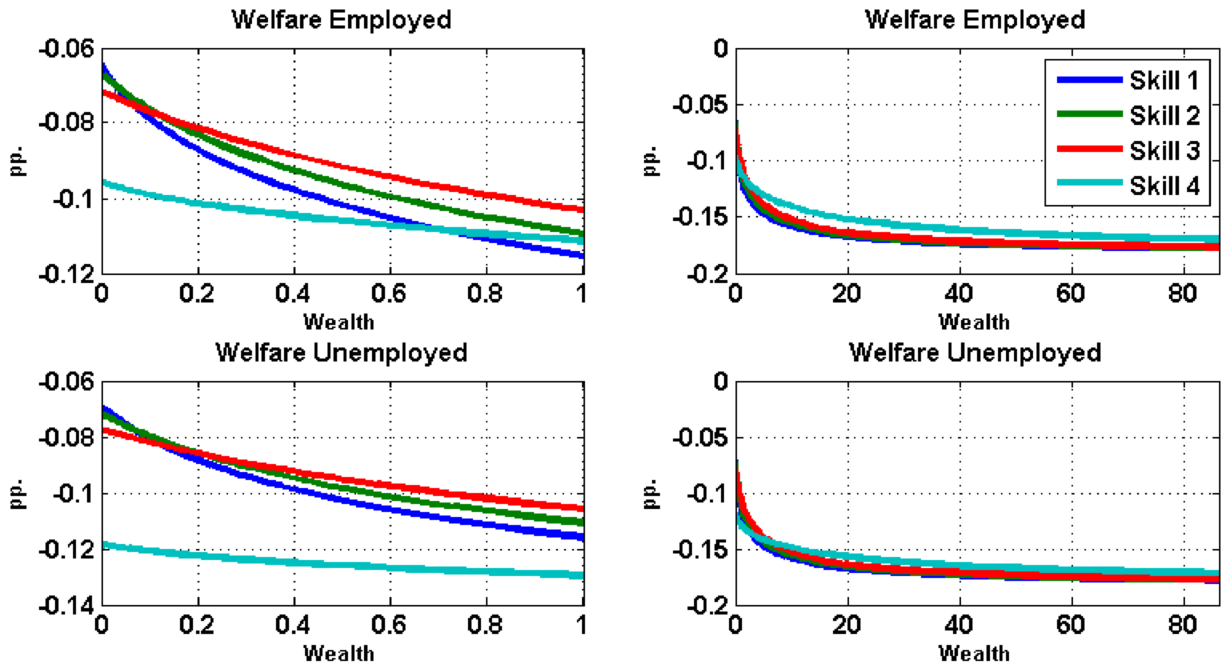
Notes: The table compares moments of the data and two variants of the model (heterogenous households, representative households). The model data are from 1,000,000 periods of simulations of the model. Each simulation is initialized with 500 periods of simulations that are dropped for the computation of the moments. In each case, we take the natural log of the data. Reported is 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. 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 autoregression coefficient. [1]: the nominal interest rate and inflation are reported in annualized percentage points. Some of the moments in the representative agent model where targeted based on 10,000 simulation runs. These targets are hit by the parameterization. The moments reported here may differ marginally from the target since the table shows moments for 1,000,000 runs.

Table 15: Model-implied means compared to nonstochastic steady state

	heterog. hh.	
	mean	steady state
Output and components		
GDP (GDP)	0.992	1.000
Consumption (c)	0.828	0.828
Investment (i)	0.149	0.150
Capacity utilization (v)	1.001	1.000
Labor market		
Unemployment $U(X)$	0.031	0.030
Long Term Unemployment $LU(X)$	0.033	0.030
Job finding rate (f)	0.718	0.725
Long Term Job finding rate (lf)	0.328	0.333
Productivity and Prices		
$GDP(X)/N(X)$	1.060	1.064
Wage $W(X)$	0.679	0.681
Inflation Π [1]	1.024	1.020
Nominal rate R [1]	1.066	1.062
Assets		
Share with $a = 0$		
P(75)/P(25)		
p_a		
Capital K		

Notes: For two variants of the model (heterogenous households, representative households) and several variables, the models compares means with aggregate fluctuations (column "mean") and without (column "steady state"). The moments are based on 1,000,000 periods of simulations of the respective model variant, beside P(75)/P(25) and Share with $a = 0$ with uses 10,000 periods. Each simulation is initialized with 500 periods of simulations that are dropped for the computation of the moments. All variables scaled exactly as they appear in the model of Section 2, with the following exception [1]: the nominal interest rate and inflation are reported in annualized percentage points.

Figure 13: Welfare Gains of Switching to $\phi_u = 0.25$ – output-specific price-adjustment costs



Notes: Same as Figure 12, with the exception that now the price setting involves output-specific adjustment costs (parameter $\gamma = 0.75$). The baseline for computing the welfare costs is the model with $\gamma = 0.75$ but $\phi_u = 0.158$.

8 Conclusions

Monetary policy affects both aggregate economic activity and the distribution of incomes and risk across households. In this paper we have assessed the distributional effects of both monetary surprises and difference in the systematic monetary response to economic activity and inflation. Toward that end, we have a New Keynesian DSGE model that features asset market incompleteness, a frictional labor market, and sticky prices. We have solved the model using global solution techniques so as to account for effects that stabilization policy may have on average markups, unemployment, and aggregate activity.

Apart from the market incompleteness, our model deliberately stays close to existing formulations of the New Keynesian model with labor market search and matching frictions, as summarized, for example, in Galí (2008). We use the model setup to quantify how monetary policy affects different segments of the population and what considerations shape which segments of the population prefer hawkish or dovish policy.

We find that contractionary monetary policy shocks lead to a pronounced increase in earnings, income, wealth, and consumption heterogeneity. Particularly for wealth and consumption

Table 16: Welfare implications of transition to more accommodative policy ($\phi_u = 0.25$) under long term unemployment

	$\phi_u = 0.25$
Social Welfare	
Average of all Households (HA)	0.1019
By Wealth Holdings	
Top 5 percent	0.0274
5-20 percent	0.0602
20-40 percent	0.0778
40-60 percent	0.0867
60-80 percent	0.1052
80-95 percent	0.1660
Bottom 5 percent	0.2534

Notes: Same as Table 12 but for the fact that we have long term unemployment.

heterogeneity, the effects are very persistent and continue to be present even once the monetary impulse on the aggregate economy has largely died out. These findings are broadly consistent with the results in the empirical literature, for example, the recent evidence by Coibion et al. (2012). These shocks also have quite heterogenous welfare effects, generally affecting households the more, the unemployed more as well as those households who hold relatively less wealth. At the same time, and holding fixed the former dimensions, it is very high-skilled workers who lose more from a monetary policy shock. This is an important caveat that wealth alone is not a sufficient statistic for assessing the distributional effects of monetary policy.

The distributional consequences of monetary shocks suggest that differences in the systematic response of monetary policy to inflation and unemployment might affect different segments of the population quite differently as well. The paper demonstrates that permanently switching to more accommodative policy benefits the wealth-poorer and the middle-class at the expense of the wealth richest segment of the population. This masks considerable heterogeneity within the group of wealth-rich households, however. In particular, wealth-rich but income-poor households are the driver of the welfare losses for this group, whereas wealth-rich households that are income rich at the same time, prefer accommodative policy as well. The reason for this distinction is that accommodative monetary policy reduces aggregate labor-income risk. This reduces the demand for savings out of a precautionary motive and, thereby, adversely affects the price of shares. This in turn, adversely affects those households whose savings are large relative to their current labor income and who, thus, seek to smooth their consumption by reducing savings. The paper, thus, suggests that wealth alone is not a sufficient statistic for assessing the distributional consequences of monetary policy. Dovish policy, in the baseline, economy benefits those who are wealth-poor relative to their earnings potential at the expense of those households for which the opposite is the case.

Last, we assess the extent to which several extensions might overturn or strengthen the results above. An important finding is the role that non-linearities in the New Keynesian Phillips curve can play in assessing the welfare effects of different systematic policies. Namely, once allowing for costs of adjustments that depend on the retailers' own production level, we demonstrate that poor households might, actually, prefer more hawkish over more dovish policy. The opposite is the case for wealth-richer households. The reason for this result is that in such a setup more accommodative monetary policy leads to higher inflation volatility. This in turn translates into higher average markups. As a result, systematically more accommodative monetary policy may well hurt the wealth-poor and benefit the rich.

The results point to considerable distributional effects of both systematic monetary policy and monetary surprises. At the same time, the results in the baseline model have kept the heterogeneity of households to a bear minimum. In future work, we plan to explore additional sources of heterogeneity. A natural starting point may be to allow for more substantial unemployment risk that affects different skill groups differently. For example is well-known that unemployment risk in recessions rises disproportionately for the lower skill groups; Elsby et al. (2010). Similarly, along with different unemployment risks, and average savings, wages of different skill groups are likely to be affected differently by monetary policy measures; Heathcote et al. (2009). Related, it would be interesting not only to look at redistribution across wealth-characteristics, but also across generations. Last, we abstract from is portfolio composition choice of households, which can affect the distributional effects of monetary policy.

the current paper focused on working-age households. We found that what matters for the distributional effects of monetary policy is the ratio of wealth to labor income, which is particularly high for retired workers. We are, therefore, working on an extension that covers age (and retirement).

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A Model Appendix

For better accessability, Table 17 presents a list of the variables used in the paper. In the following, equilibrium conditions of some sectors of the economy are derived. At the end of this section, steady-state conditions are derived and listed.

A.1 Capital-Producing Sector

Using q as the Lagrange multiplier for the law of motion of capital, we obtain the following first-order conditions with respect to i, v, and k':

$$
\begin{aligned}
&r(X) = q\delta'(v) \\
&q\zeta'\left(\frac{i}{k}\right) = 1 \\
&\mathbb{E}Q(X,X')J'_K(X',k') = q
\end{aligned}
$$

The envelope condition with respect to k yields:

$$J'_K(X,k) = r(X)v + q\left(1 - \delta(v) + \zeta\left(\frac{i}{k}\right) - \zeta'\left(\frac{i}{k}\right)\frac{i}{k}\right).$$

Combining them and imposing an equilibrium condition $k = K$, we obtain the following two conditions that characterize:

$$
\begin{aligned}
&r(X)\zeta'\left(\frac{i}{K}\right) = \delta'(v) \\
&\frac{1}{\zeta'(i/K)} = \mathbb{E}Q(X,X')\left[r'(X')v' + \frac{1}{\zeta'(i'/K')}\left(1 - \delta(v') + \zeta\left(\frac{i'}{K'}\right)\right) - \frac{i'}{K'}\right]
\end{aligned}
$$

These conditions characterize investment $i(X)$ and utilization $v(X)$ and indirectly the law of motion for capital stock $K'(X)$.

A.2 Final Good Producer

The first-order condition with respect to y_j for the problem of the representative final good producer implies the following for $\forall j$:

$$y_j = \left(\frac{P_j}{P(X)}\right)^{-\epsilon} y$$

Notice that the zero profit condition for final good producers implies:

$$P(X)y = \int_0^1 P_j y_j dj$$

Table 17: List of Variables

Variable	Description
$X = (K, N, Z, D, \mu)$	Vector of aggregate state variables
K	Aggregate capital stock
N	Total employment
Z	Total factor productivity (TFP) shock
D	Monetary policy shock
$\mu = (e, s, a) \in \mathcal{M}$	Type distribution of households
G	Law of motion of X
w	Wage per efficiency unit
h	Rental rate of labor (per efficiency unit)
r	Rental rate of capital
p_b	Price of a risk-free one-period discount bond
p_a	Price of a share of mutual funds
d_a	Dividends per share of the mutual funds
P	Price of the final good
P_j	Price of the intermediate good j
Π	Inflation rate
$e \in \{0, 1\}$	Employment status (0: unemployed, 1: employed)
$s \in S$	Skill level
$a \in A \subseteq \mathbb{R}^+$	Share holdings of the mutual funds
$W(X, e, s, a)$	Households' value function
c	Consumption
$a' = g_a(X, e, s, a)$	Optimal decision rule of households with respect to share holdings
$c = g_a(X, e, s, a)$	Optimal decision rule of households with respect to consumption
$Q(X, X')$	Aggregate discount factor
$J_L(X, s)$	Value function for labor agencies
f	Job-finding rate
M	Number of new matches created
$U = 1 - N$	Number of unemployed households
V	Number of vacancy postings
$J_K(X, k)$	Value of capital-producing firm
$J_I(X, P_{j,-1})$	Value function for intermediate good producer
y	Output of a final good producer
y_j	Output of an intermediate good j
v	Utilization rate of capital
i	Investment
ℓ_j	Labor inputs used by an intermediate good producer
k_j	Capital inputs used by an intermediate good producer
τ	Labor tax rate
b	Unemployment insurance benefits per efficiency unit
R	Risk-free nominal rate

Moreover, since we will focus on a symmetric equilibrium in which (y_j, P_j) are the same for all j, we have $P(X) = P_j$ and $y = y_j$ for $\forall j$ in equilibrium. Going back, the following first-order condition for good j characterizes the demand function used for the problem of the monopolistic intermediate good producer's problem:

$$y_j(P_j, X) = \left(\frac{P_j}{P(X)}\right)^{-\epsilon} y(X) \tag{41}$$

where, in equilibrium, $y_j(P_j, X) = y_j(P(X), X) = y(X)$ for $\forall j$.

A.3 Intermediate Good Producer

Notice that the problem of an intermediate good producer j can be split into two problems: (i) the cost minimization problem given output $\overline{y}_j$, and (ii) the choice of the price P_j given the demand function of the final good producer and the solution to the cost minimization problem given output level y_j. Let's look at the problems one by one.

The cost-minimization problem of an intermediate good producer can be characterized as follows:

$$\min_{k_j, \ell_j} \quad r(X)v(X)k_j + h(X)\ell \tag{42}$$

$$\text{s.t.} \qquad \overline{y}_j = Zk_j^{\theta}\ell_j^{1-\theta} \tag{43}$$

Arranging the first-order conditions, we can obtain the following two equations:

$$\frac{r(X)v(X)}{h(X)} = \frac{\theta\ell_j}{(1-\theta)k_j} \tag{44}$$

$$\overline{y}_j = Zk_j^{\theta}\ell_j^{1-\theta} \tag{45}$$

Plugging them back into the total cost yields:

$$\text{total cost} = \left(\frac{1}{\theta}\right)^{\theta}\left(\frac{1}{1-\theta}\right)^{1-\theta}\frac{(r(X)v(X))^{\theta}h(X)^{1-\theta}}{Z}\overline{y}_j \tag{46}$$

This implies:

$$\text{marginal cost} = m(X) = \left(\frac{1}{\theta}\right)^{\theta}\left(\frac{1}{1-\theta}\right)^{1-\theta}\frac{(r(X)v(X))^{\theta}h(X)^{1-\theta}}{Z} \tag{47}$$

Second, an intermediate good producer j sets the price of its product P_j, taking the demand function of the final good producer (41) and prices as given. The profit maximization problem of an intermediate good producer j can be recursively characterized as follows:

$$J_I(X, P_{j,-1}) = \max_{P_j} \left\{ \left(\frac{P_j}{P(X)}\right)^{-\epsilon} y(X) \left(\frac{P_j}{P(X)} - m(X)\right) - \frac{\psi}{2}\left(\frac{P_j}{P_{j,-1}} - \overline{\Pi}\right)^2 \bar{y} + \mathbb{E}Q(X, X')J_I(X', P_j) \right\} \quad (48)$$

subject to $X' = G(X)$. $m(X)$ is the marginal cost defined in (47). It is necessary because the price adjustment cost depends on the change in the price from the previous period ($\Pi_{j,-1}$) to the current period (P_j). However, as shown below, we will not need to keep track of $P_{j,-1}$ in our computations. Also notice that the demand function by the final good firm (41) is already taken into account. The first-order condition with respect to P_j and the envelope condition are the following:

$$y(X)\left(\frac{P_j}{P(X)}\right)^{-\epsilon-1}\left[\frac{(1-\epsilon)}{P(X)}\left(\frac{P_j}{P(X)}\right) + \frac{m(X)\epsilon}{P(X)}\right] - \frac{\psi}{P_{j,-1}}\left(\frac{P_j}{P_{j,-1}} - \overline{\Pi}\right)\bar{y} + \mathbb{E}Q(X, X')J'(X', P_j) = 0$$

$$J_I'(X, P_{j,-1}) = \psi\left(\frac{P_j}{P_{j,-1}^2}\right)\left(\frac{P_j}{P_{j,-1}} - \overline{\Pi}\right)\bar{y}$$

Combining the two, applying $\Pi(X) = P(X)/P_{-1}(X)$, and imposing the symmetric equilibrium condition $P = P_j \; \forall j$:

$$(1 - \epsilon + m(X)\epsilon)\, y(X) - \psi\Pi(X)(\Pi(X) - \overline{\Pi})\bar{y} + \mathbb{E}Q(X, X')y(X')\psi\Pi(X')(\Pi(X') - \overline{\Pi}) = 0 \quad (49)$$

Notice that, as mentioned, it is no longer necessary to keep track of past prices. Instead, Euler equation (49) implicitly characterizes the inflation rate of intermediate and final goods $\Pi(X)$.

A.4 Steady-State Conditions

The following equations characterize the labor market in the steady state:

$$J_L^*(s) = (h^* - w^*)s + Q^* \sum_{s'} \pi_{s,s'} J_L^*(s')$$

$$M^* = \gamma((1 - N^*) + \lambda N^*)^{\alpha}(V^*)^{1-\alpha}$$

$$\kappa = \frac{M^*}{V^*}\int_{\mathcal{M}} J_L^*(s)\; d\;\mu$$

$$\lambda N^* = M^*$$

In the steady state, the optimal decisions of capital-producing firms can be characterized as follows. Notice that we assume $\zeta(i^*/K^*) = i^*/K^*$, $\zeta'(i^*/K^*) = 1$, $\delta(v^*) = \delta^*$

$$\delta^* K^* = i^*$$
$$1 = Q^*[r^* + 1 - \delta^*]$$

The optimal decisions of the intermediate good producers in the stead-state equilibrium are characterized by the following:

$$\frac{r^* v^*}{h^*} = \frac{\theta L^*}{(1-\theta)K^*}$$
$$m^* = \left(\frac{1}{\theta}\right)^{\theta} \left(\frac{1}{1-\theta}\right)^{1-\theta} \frac{(r^*)^{\theta}(h^*)^{1-\theta}}{Z^*}$$
$$1 - \epsilon + m^* \epsilon = 0$$

B Nonlinearities in the New Keynesian Phillips curve

Section 7 argued that non-linearities in price setting may mean that, for given average levels of inflation, higher inflation volatility translates into higher markups and less economic activity on average. This, in turn, was found to counter the case for more accommodative policy. This appendix provides analytical results for a special case. Focus on the representative-agent economy and the case, when firm-specific price-setting costs are maximal, $\gamma = 1$. Now assume, last, that there are no fluctuations in $Q(X, X')\frac{y(X')}{y(X)}$ (the latter, up to second order would be the case in the simple three-equation New Keynesian model with log utility). Then, the first-order condition for price setting is

$$\psi\Pi(X)(\Pi(X) - \overline{\Pi}) = 1 - \epsilon + \psi\beta\mathbb{E}\Pi(X')(\Pi(X') - \overline{\Pi}) + \epsilon\, mc(X) + \frac{\epsilon}{2}(\Pi(X) - \overline{\Pi})^2.$$

Here $mc(X)$ marks marginal cost. Take a second-order expansion around the steady state and fix average inflation to $\mathbb{E}\Pi(X) = \overline{\Pi}$. Then, up to second order, $\mathbb{E}mc(X) - \overline{mc} = \frac{\psi}{\epsilon}[1-\beta-\epsilon]V(\Pi(X))$. Since $\epsilon > 1$ and $\beta > 0$, we have that expected marginal costs fall in inflation volatility. Since marginal costs are the inverse of the markup in the Rotemberg model, the average markup rises with inflation volatility. Quantitatively, how this translates into average output in the economy will depend on the wealth effect. If labor supply is inelastic (as it is in our model) a fall in marginal costs will require more of an adjustment in the quantities than if labor supply is elastic.

C Computation Appendix

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 Krusell and Smith (1997) and is closely related to the solution method based on reference distributions described in Reiter (2002) and Reiter (2010), whose work follows the ideas in Krusell and Smith (1998).[26]

[26] In earlier versions of the paper we used an approach closer to Krusell and Smith (1998), in which we forecasted

1. Following Reiter (2010) we approximate the aggregate state of the economy by $X = (K, N, Z, D)$ 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 S, employment state E and a grid on the wealth distribution. All agents use this function to construct their forecasts about the evolution of the economy. Note that this distribution function need not be linear (or log-linear) in X. Rather, it can involve transformations of X, such as higher-order terms. Form a grid for X.

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

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. To have a short hand, we denote these guesses by $\Sigma(X)$.[27]

4. Given this 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 that were obtained in the previous step, iterate on the value function of households.

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

      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 $a' = g_a(X, e, s, a)$ and $c = g_c(X, e, s, a)$ 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 (5) 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.

the the expectation terms in the firms euler equations and asset prices. The current method allows for a faster solution of the model. Results were similar across methods.

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

(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 a 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 $P_a(X)$.
   iv. Conditional on $\hat{p}_a$, and the aggregate state variables in period t, solve the problem of 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.

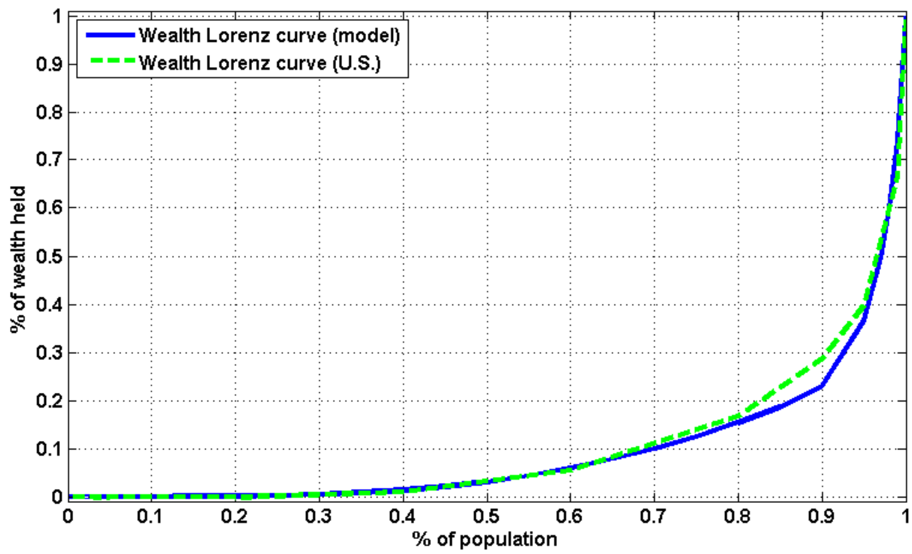
(f) The previous step generates a time series of household distributions $\{\mu\}_{t=0}^{T}$. Drop the first T_0 periods. Using the time series for $t = T_0 + 1, ..., T$ construct a new reference distribution function $\hat{\mu}'$ following Reiter (2002).

(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.

D Details on the calibration

Figure 14 shows the wealth Lorenz curve for the U.S. as a dashed line. The data are from Díaz-Giménez et al. (2011), who use the 2007 Survey of Consumer Finances. The model matches the wealth distribution in the U.S. economy. A solid line shows the model's steady-state counterpart.

Figure 14: Wealth Inequality



Notes: Wealth Lorenz curve in the model (blue solid line) against Lorenz curve of wealth for the U.S. (green dashed line).

Table 18: "Wall Street's" and "Main Street's" income sources

Wealth perc.	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	93	93	89	81	79	63	27
Financial income	0	1	6	14	17	34	72
Transfers	7	6	5	5	4	3	1

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.

E Cashless limit

Our model economy operates under the assumption that frictions from holding cash are negligible. In doing so, we follow Woodford (1998) and a large fraction of the New Keynesian literature. This appendix is meant to make clear how monetary policy can control the price level in such an environment. The appendix provides one (highly stylized) environment in which the cashless limit would apply. The appendix serves to highlight some of the implicit assumptions that we make. We resort to time notation to keep the notational burden low.

E.1 Financial services firms

In the following, we introduce money in the production function. References are Fischer (1974) and, more recently, Benhabib et al. (2001). We will assume that holding monetary balances facilitates intermediation. Suppose that next to the firms discussed so far, there is a measure one of what we will label "financial services" firms. These firms produce financial services, x_t, using central bank reserves (high-powered money):

$$x_t = \gamma(M_t/P_t)^{\zeta}, \quad \gamma > 0, \zeta \in (0,1).$$

In addition, the firms can hold private or government debt. Assume, for simplicity that these are the only firms that can hold government debt. There is no entry or exit into this industry.

We could assume here that financial services are complements to the production of cash-flow by the mutual funds (in line with the intermediation role alluded to above). This would – unnecessarily – alter the first-order conditions that we spelled out in the main text. Instead, we focus on a simpler case, and assume that financial services add to the stock of the consumption good. Note that this fixes – by assumption – the relative price of financial services and final goods to unity. The aggregate resource constraint (30) changes to

$$y_t + x_t = c_t + i_t + \kappa V_t + \Xi + \frac{\phi_\Pi}{2}\left(\Pi_t - \overline{\Pi}\right)^2$$

E.2 Central Bank

The government issues both money and government bonds. Money does not pay interest. Money is issued through fully collateralized one-period lending. As collateral, the government accepts both one-period private-sector nominal debt and one-period nominal government debt. Both of these instruments are traded in a competitive market. Assume that the supply of nominal government debt (even if small) exceeds the supply of money balances. In equilibrium, therefore, the interest rate of government debt and private-sector debt will be equalized. We use R_t for both the gross interest rate on private-sector debt and government debt. Financial services firms can borrow reserves M_t from the central bank for one period. Doing so, they forfeit the interest earned on the bond. Reserves are to be fully repaid in $t+1$.

E.3 First-order condition of financial services firm

The financial services firms' first-order condition for reserve balances (the money demand equation) is given by

$$1 - \gamma\zeta \left(\frac{M_t}{P_t}\right)^{\zeta} = \beta E_t Q_{t,t+1} \frac{1}{\Pi_{t+1}}$$

If prices are rigid, by adjusting the supply of nominal money balances, the central bank can affect the stochastic discount factor. The effect on nominal rates R_t follows from the bond-holding first-order condition (19).

What remains to be argued is that the monetary authority retains control of the price level even if real balances are very small.

E.4 Consolidated government budget constraint

The government issues one-period nominal government debt at interest rate R_t. The government's flow budget constraint (anticipating (23)) is given by

$$B_t^g + M_t = B_{t-1}^g R_{t-1} + M_{t-1} - \tau_t^F$$

where the latter are lump-sum taxes leveled on the financial-services firms. For concreteness, let the government target a fixed real value of government debt $\frac{B_t^g}{P_t} = \overline{b}^g$. Assume that $\overline{B}$ is chosen so that the implied B_t^g is strictly larger than the maximum money demand M_t in all states of the world. Lump-sum taxes on financial services firms evolve according to:

$$-\tau_t^F = \frac{B_t^g}{P_t} + \frac{M_t}{P_t} - \frac{B_{t-1}^g}{P_{t-1}} \frac{R_{t-1}}{\Pi_t} + \frac{M_{t-1}}{P_{t-1}} / \Pi_t,$$

so that $\tau_t^F = \overline{b}^g(R_{t-1}/\Pi_t - 1) - (m_t - m_{t-1}/\Pi_t)$. This makes clear the implicit assumption on taxation in our economy. Namely, every period, the government rebates the value of seignorage less the real interest payments on debt to the financial sector.

E.5 Link to the baseline model

The model in the main body of the text (Section 2) emerges as the limiting case when $\gamma \to 0$ and the target level of government debt, $\overline{b}^g$ goes to zero as well. Namely, in such a way that $M_t/P_t \Rightarrow 0$, but $\overline{b}^g > M_t/P_t$ for all states of the world.

F Spare tables and figures

This appendix collects spare tables and figures from the paper.

Table 19: Model-implied means compared to nonstochastic steady state

	heterog. hh.		represent. hh.	
	mean	steady state	mean	steady state
Output and components				
GDP (GDP)	1.001	1.000	1.001	1.000
Consumption (c)	0.828	0.828	0.828	0.828
Investment (i)	0.150	0.150	0.150	0.150
Capacity utilization (v)	0.998	1.000	0.999	1.000
Labor market				
Employment $N(X)$	0.940	0.940	0.940	0.940
Unemployment $U(X)$	0.060	0.060	0.060	0.060
Vacancies (V)	0.135	0.135	0.136	0.135
Job finding rate (f)	0.616	0.610	0.617	0.610
Productivity and Prices				
$GDP(X)/N(X)$	1.064	1.064	1.064	1.064
Wage $W(X)$	0.681	0.681	0.681	0.681
Inflation Π [1]	1.019	1.020	1.020	1.020
Nominal rate R [1]	1.061	1.062	1.061	1.062
Assets				
Share with $a = 0$	10.1%	10.0%	N/A	N/A
P(75)/P(25)	15.10	15.05	N/A	N/A
p_a	18.62	18.61	18.57	18.61
Capital K	10.06	10.00	10.06	10.00

Notes: For two variants of the model (heterogenous households, representative households) and several variables, the models compares means with aggregate fluctuations (column "mean") and without (column "steady state"). The moments are based on 1,000,000 periods of simulations of the respective model variant, beside P(75)/P(25) and Share with $a = 0$ with uses 25,000 periods. Each simulation is initialized with 500 periods of simulations that are dropped for the computation of the moments. All variables scaled exactly as they appear in the model of Section 2, with the following exception [1]: the nominal interest rate and inflation are reported in annualized percentage points.

Table 20: Welfare effects of a TFP shock by skill, employment, and wealth

Wealth level	skill (low to high), employed			
	s_1	s_2	s_3	s_4
Top 5%	0.46	0.44	0.42	0.34
Median	0.33	0.30	0.27	0.26
Zero wealth	0.26	0.24	0.23	0.24
Wealth level	**skill (low to high), unemployed**			
	s_1	s_2	s_3	s_4
Top 5%	0.46	0.45	0.43	0.41
Median	0.34	0.32	0.29	0.38
Zero wealth	0.30	0.27	0.26	0.37

Notes: The table shows the welfare gains of a one standard deviation positive TFP shock for selected wealth levels. We look at agents that own wealth so that they are exactly at the top 5%, at the median, and at the bottom of the wealth distribution. Conditional on being in the respective wealth group, the table tabulates the welfare losses by current skill and employment status. Welfare is measured by the percentage increase in life-time consumption, compared with the initial condition.

F.1 Means and welfare cost of shocks

F.2 More accommodative monetary policy

F.3 Firm-specific price-setting costs

Table 21: Moments: baseline vs. accommodative ($\phi_u = 0.25, 0.5$)

	Baseline ($\phi_u = 0.158$)		Accommodative ($\phi_u = 0.25$).		Accommodative ($\phi_u = 0.5$).	
	Mean	Std	Mean	Std		
Output and components						
GDP (GDP)	1.001	1.35	1.001	1.247	1.002	1.08
Consumption (c)	0.828	0.86	0.829	0.803	0.829	0.70
Investment (i)	0.150	3.56	0.150	3.301	0.151	2.88
Capacity utilization (v)	0.998	0.55	0.998	0.469	0.997	0.34
Labor market						
Employment $N(X)$	0.940	0.52	0.941	0.431	0.942	0.30
Unemployment $U(X)$	0.060	8.63	0.059	7.243	0.058	5.23
Vacancies (V)	0.135	6.99	0.135	5.808	0.135	4.13
Job finding rate (f)	0.616	4.22	0.618	3.486	0.622	2.46
Productivity and Price s						
$GDP(X)/N(X)$	1.064	0.88	1.064	0.860	1.063	0.81
Wage $W(X)$	0.681	0.40	0.681	0.387	0.681	0.36
Inflation Π [1]	1.019	0.64	1.018	0.773	1.011	1.04
Nominal rate R [1]	1.061	0.66	1.059	0.805	1.052	1.07
Assets						
Share with $a = 0$	10.1%					
P(75)/P(25)	15.10					
p_a	18.62					
Capital						

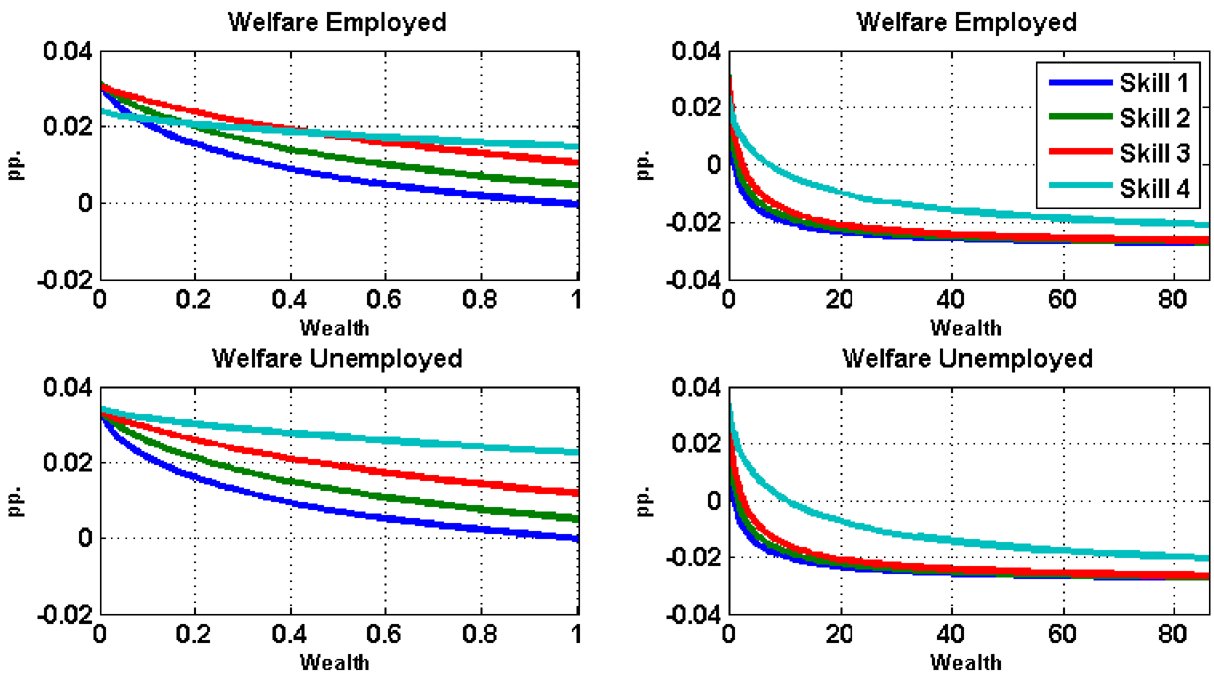
Notes: The table compares the long-run means and standard deviations for two variants of the heterogeneous agents model: the baseline, and the model with more unemployment-centred policy ($\phi_u = 0.5$). The moments are based on 1,000,000 periods of simulations of the respective model variant, beside P(75)/P(25) and Share with $a = 0$ with uses 25,000 periods. Each simulation is initialized with 500 periods of simulations that are dropped for the computation of the moments. All variables scaled exactly as they appear in the model of Section 2, with the following exception [1]: the nominal interest rate and inflation are reported in annualized percentage points.

Table 22: Moments: baseline vs. accommodative ($\phi_u = 0.25$) – with output-specific price-setting costs –

	$\phi_u = 0.158$		Accommodative ($\phi_u = 0.25$).	
	Mean	Std	Mean	Std
Output and components				
GDP (GDP)	0.998	1.412	0.997	1.356
Consumption (c)	0.826	0.907	0.825	0.887
Investment (i)	0.150	3.691	0.150	3.546
Capacity utilization (v)	0.996	0.570	0.995	0.489
Labor market				
Employment $N(X)$	0.938	0.560	0.938	0.477
Unemployment $U(X)$	0.0618	8.518	0.0623	7.074
Vacancies (V)	0.133	7.187	0.132	6.047
Job finding rate (f)	0.607	4.488	0.604	3.813
Productivity and Price s				
$GDP(X)/N(X)$	1.064	0.899	1.063	0.920
Wage $W(X)$	0.681	0.403	0.681	0.412
Inflation Π[1]	1.022	0.677	1.024	0.857
Nominal rate R[1]	1.064	0.708	1.066	0.892
Assets				
Share with $a = 0$				
P(75)/P(25)				
p_a				
Capital				

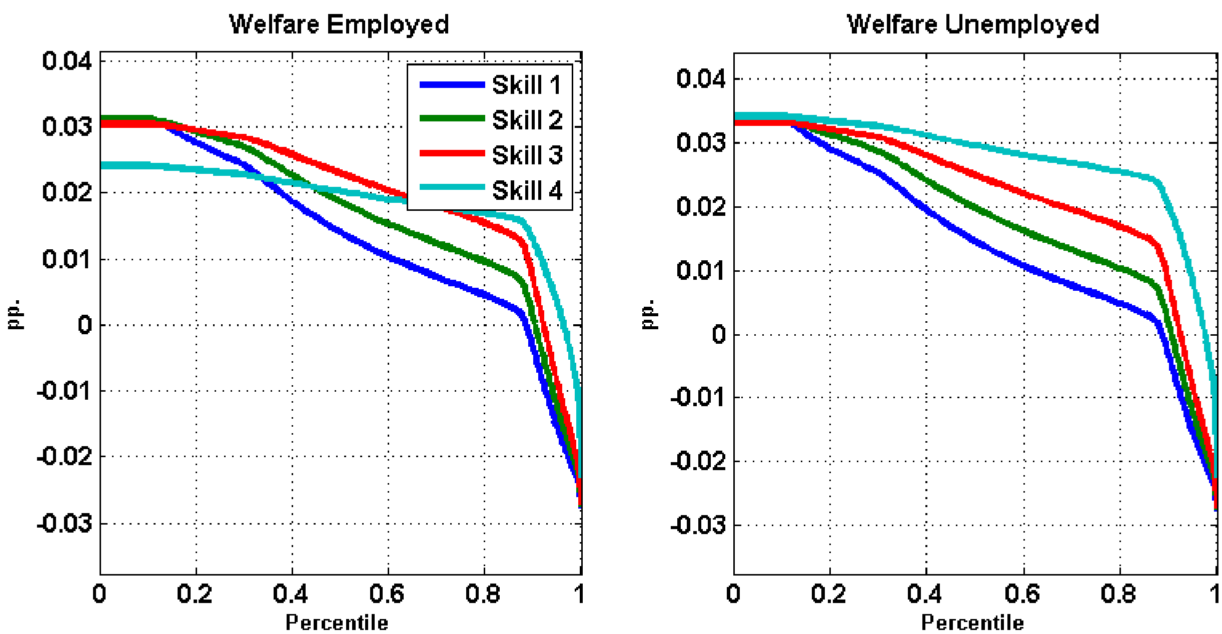
Notes: Same as Table **??**, except that now both the low and the high unemployment-response case build on the model with firm-specific price-setting costs, introduced in Section 7.2. All variables scaled exactly as they appear in the model of Section 2, with the following exception [1]: the nominal interest rate and inflation are reported in annualized percentage points.

Figure 15: Welfare Gains of Switching from Baseline to $\phi_u = 0.25$



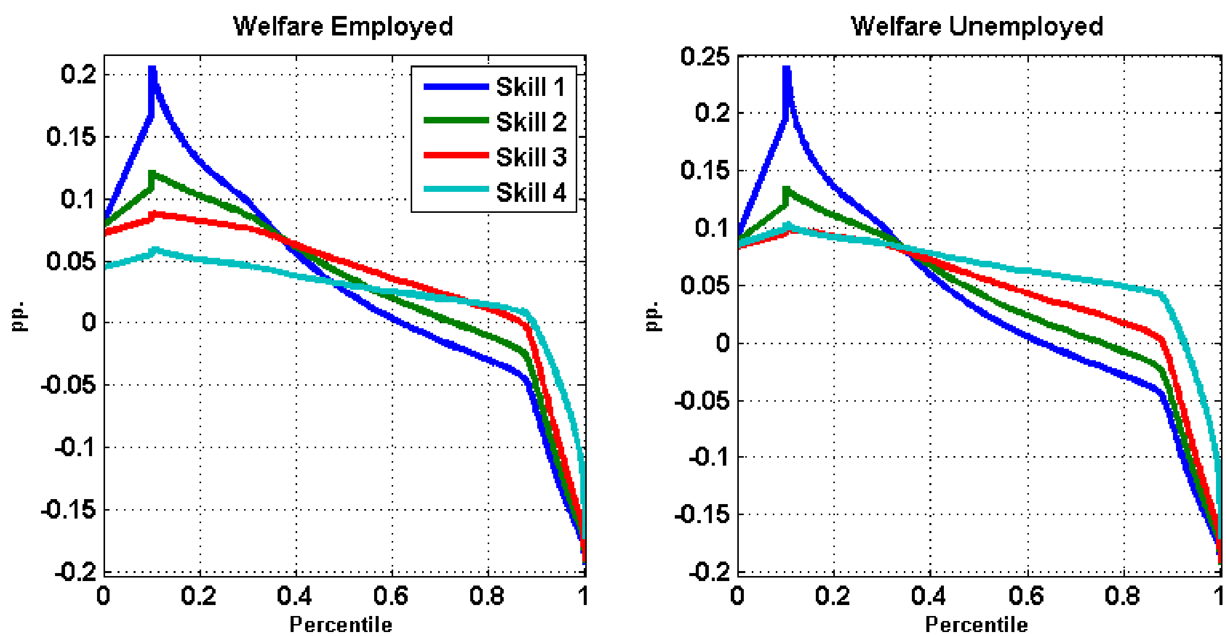
Notes: This figure shows the welfare changes from a switch from the baseline monetary policy rule to one with $\phi_u = 0.25$ by the households' individual states. First row: conditional on being employed. Second row: conditional on being unemployed. In each of the panels, the four lines refer to the skill level (ordered from lowest to highest). Shown is the welfare gain in terms of a percentage change of households lifetime consumption (y-axis) for different wealth levels (x-axis). The only difference between the panels in the left column and those in the right is the range shown on the x-axis. In the left column, the range goes from 0 to one, covering about 2/3 of the households. The panels on the right show all asset levels.

Figure 16: Welfare Gains of Switching from Baseline to $\phi_u = 0.25$



Notes: This figure shows the welfare changes from a switch from the baseline monetary policy rule to one with $\phi_u = 0.25$ by the households' individual states. Left: conditional on being employed. Right: conditional on being unemployed. In each of the panels, the four lines refer to the skill level (ordered from lowest to highest). Shown is the welfare gain in terms of a percentage change of households lifetime consumption (y-axis) for different *percentiles* of the wealth distribution (x-axis).

Figure 17: Welfare Gains of Switching from Baseline to $\phi_u = 0.5$



Notes: This figure shows the welfare changes from a switch from the baseline monetary policy rule to one with $\phi_u = 0.5$ by the households' individual states. Left: conditional on being employed. Right: conditional on being unemployed. In each of the panels, the four lines refer to the skill level (ordered from lowest to highest). Shown is the welfare gain in terms of a percentage change of households lifetime consumption (y-axis) for different *percentiles* of the wealth distribution (x-axis).