Monetary Policy and Inequality: How Does One Affect the Other?*

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Abstract

This paper studies a labor-supply-side channel affecting the relationship between monetary policy and income inequality. To this end, I build a heterogeneous-agent New Keynesian economy with indivisible labor in which both macro and micro labor supply elasticities are endogenously generated. First, I find that monetary policy shocks have distributional consequences due to a substantial heterogeneity in labor supply elasticity across households. Second, a more equal economy is associated with more effective monetary policy in terms of output. I document supporting empirical evidence for the key mechanism of the model using micro-level data and state-level data in the U.S.

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1 Introduction

In recent years, how monetary policy and inequality affect each other has been a primary concern of economists and policy makers (Holm, 2018; Kaplan et al., 2018; Gornemann et al., 2021). Previous contributions to the literature have devoted a great deal of effort to studying this issue, but they have focused mainly on transmission channels through asset markets, such as portfolio choice (Kaplan et al., 2018), interest rate exposure (Auclert, 2019), or financial segmentation (Enders, 2020). For most households, labor income is the main source of income regardless of differences in income composition. Moreover, the labor supply responses to monetary policy shocks can differ significantly across households, depending on the level of asset holdings and labor productivity. In this regard, a labor-supply-side story is also of immediate relevance for understanding both aggregate and disaggregate effects of monetary policy, but this channel has received relatively little attention in the literature.[1] Accordingly, this paper studies bilateral linkages between monetary policy and income inequality by focusing on a supply-side channel in the labor market.

To this end, I develop a simple dynamic stochastic general equilibrium (DSGE) New Keynesian model that employs a continuum (measure one) of heterogeneous households, the central bank, the government, a mutual fund, and firms. In the economy, individual households are subject to idiosyncratic shocks of time preference (as in Krusell and Smith, 1998) and labor productivity (as in Aiyagari, 1994).[2] Households cannot issue any assets contingent on their future idiosyncratic risks, which implies that asset markets are incomplete, as in Huggett (1993) and Aiyagari (1994). The market incompleteness, along with borrowing constraints, helps generate substantial heterogeneity across characteristics of individual households, including wealth, income, employment, and consumption. Following Chang and Kim (2007), it is assumed that a household indivisibly decides hours of work. As is well-known, extensive margins for time devoted to work are important in accounting for the variation in total hours worked. Particularly, in the heterogeneous-agent model economy with indivisible labor, both micro and macro labor supply elasticities are endogenously generated. For the remaining blocks of the model economy, I employ standard assumptions in the New Keynesian literature: nominal prices are rigid, monopolistically competitive producers set prices, and a central bank follows the conventional Taylor rule.

One of the key findings is that a labor-supply-side channel plays a crucial role in accounting for the distributional consequences of monetary policy. The main mechanism of the effects of a monetary policy shock on the income distribution is through heterogeneity in the elasticity of labor supply across households. The discrete labor supply assumption endogenously creates a decreasing pattern of labor supply elasticity over the level of income: the elasticity of income-poor households is relatively large, while that of rich households is nearly zero. This implies that households in the

[1] Gornemann et al. (2021) consider a heterogeneous-agent New Keynesian economy with search-and-matching frictions. The distributional effects of monetary policy in their model can be interpreted as the result of heterogeneous unemployment risks across households.

[2] In this paper, I focus on a transitory component of the dynamics of labor productivity and do not consider the permanent component. Thus, transitory labor-income heterogeneity is of great importance for the relationship between monetary policy and income inequality.

bottom of the income distribution increase employment significantly following a monetary expansion. As a result, the rise in employment of the income-poor households substantially increases their labor income, thereby reducing income inequality. In the benchmark model, a 100-basis-point expansionary monetary policy shock leads households in the bottom quartile to increase earnings by 4 percent relative to the average, while the relative earnings for the households in the top quartile fall by 0.3 percent. Monetary policy shocks also result in asymmetric effects on earnings, depending on relative responses of employment and of average earnings. The poor benefit from an increase in employment, whereas the rich benefit from a rise in average earnings in a relative sense. Using micro-level data in the U.S., I provide supportive empirical evidence for the different responses to monetary policy shocks in terms of employment and the asymmetric effects on earnings across the income distribution.

Second, the long-run level of inequality greatly matters for the effectiveness of monetary policy.[3] Quantitatively, a 10-percent-lower income Gini coefficient increases the monetary policy effectiveness by around 30 percent. The main linkage between these two is aggregate labor supply elasticity. The indivisible labor supply assumption in the heterogeneous-agent model can endogenously generate the reservation wage distribution. This allows us to uncover the labor supply curve of the economy. Since a degree of heterogeneity in the economy affects the shape of the reservation wage schedule, there is a tight link between inequality and labor supply elasticity. In a low-inequality economy, the elasticity of labor supply is larger since the reservation wage distribution is more concentrated, which implies that more marginal workers are placed around the market wage. As a result, the larger aggregate labor supply elasticity produces the greater output response monetary policy shocks, implying that a low-inequality economy has a flatter New Keynesian Philips curve (NKPC). Therefore, a more equal society is associated with more effective monetary policy in terms of output, *ceteris paribus*. Using state-level panel data in the U.S., I document supporting empirical evidence for the model result that the effects of monetary policy shocks on GDP or employment are larger for low-inequality states.

Related Literature

Some recent papers provide an insightful analysis of the redistributive effects of monetary policy. Auclert (2019) finds that the effects of monetary policy on aggregate consumption tend to be amplified by redistribution channels. Kaplan et al. (2018) introduce two types of assets with different degrees of liquidity and different returns into a New Keynesian model. They find that the indirect effects of an unexpected fall in interest rates, which operate through a general equilibrium (e.g., an increase in labor demand), dominate the direct effects (i.e., the intertemporal substitution effects). Gornemann et al. (2021) consider a heterogeneous-agent New Keynesian economy in which matching frictions create countercyclical labor-market risk. The authors find that wealth-rich or retired households tend to favor inflation targeting. The current paper differs from the previous studies on the transmission mechanism of monetary policy in the presence of incomplete markets in that (i) this paper deals with the distributional effects of *unsystematic* changes in monetary policy actions;[4] and (ii) the

[3] The “effectiveness of monetary policy” is defined as the extent to which monetary policy affects output, i.e., the output responsiveness.

[4] The main focus of Gornemann et al. (2021) is on the heterogeneous welfare effects of *systematic* monetary policy.

key monetary transmission mechanism for the distributional effects is generated by employment dynamics induced by different labor supply elasticities across households. Additionally, there have been some empirical analyses on how the actions of the monetary authority affect inequality. The key contributions are Coibion et al. (2017), Mumtaz and Theophilopoulou (2017), and Furceri et al. (2018). Their main finding is that a contractionary monetary policy shock increases inequality, which is consistent with the model result in this paper.[5]

Most of the previous literature regarding the relation between inequality and monetary policy has mainly focused on one direction of the relation—the impact of monetary policy on inequality. There have been a few studies on the other direction—*the impact of inequality on the effectiveness of monetary policy*. Kim (2017) and Cravino et al. (2020) document the channels of different frequency of price changes and heterogeneous composition of consumption goods across households. Using a menu-cost model with vertically differentiated products and heterogeneous consumers, Kim (2017) concludes that the impact of monetary policy on real output decreases when there are more low-income consumers in the economy. Similarly, Cravino et al. (2020) consider a quantitative New-Keynesian model with heterogeneous households where sectors are heterogeneous in their frequency of price changes. They find that a realistic change in inequality does not substantially affect the responses of aggregate prices and of output to monetary policy. The current paper contributes to the literature by emphasizing the role of different aggregate labor supply elasticity depending on degree of inequality in the causal relation between inequality and the effectiveness of monetary policy. The main result here is supported by empirical papers in the literature, such as Alpanda and Zubairy (2017) and Voinea et al. (2018).[6] There are a couple of studies that speak to the importance of long-run inequality for monetary policy. Holm (2018) studies the effect of the long-run level of income risk on monetary policy and provides analytical solutions. Luetticke (2021) studies the importance of wealth inequality for monetary policy.

The work that is probably closest to this paper is Chang and Kim (2007), who introduce extensive margins of labor supply in heterogeneous agent general equilibrium models to study business cycle fluctuations. The present paper differs from Chang and Kim (2007) in that its main focus is on accounting for both aggregate and disaggregate effects of monetary policy rather than business cycles fluctuations. This paper is also related to the literature that discusses the relation between the long-run level of inequality and government spending multiplier (Brinca et al., 2016; Yang, 2017)[7] and to studies that investigate importance of micro-level heterogeneity in the propagation of aggregate shocks (e.g., Werning (2015) and Krueger et al. (2016)).[8]

[5] Holm et al. (2021) empirically document the dynamic responses of income, consumption, and saving along the liquid asset distribution of households and find that the impact consumption response is closely related to interest rate exposure.

[6] Using Romanian data, Voinea et al. (2018) find that lower inequality is associated with stronger effectiveness and higher homogeneity of monetary policy transmission. Alpanda and Zubairy (2017) also provide empirical evidence that the effects of monetary policy are less powerful during periods of high household debt.

[7] Brinca et al. (2016) study the relation between wealth inequality and the magnitude of fiscal multipliers. Similarly, Yang (2017) investigates the relationship between income inequality and the local government spending multipliers using rich historical state-level data on military procurement and inequality.

[8] Werning (2015) argues that the effect of market incompleteness on the interest rate elasticity of aggregate demand depends on the cyclicality of liquidity and of income risk. Krueger et al. (2016) study the importance of household

The rest of this paper is organized as follows. Section 2 introduces a heterogeneous-agent New Keynesian model with indivisible labor. Section 2 discusses calibration for the parameters used in the model economy. Main results are discussed in Section 4. Section 5 presents supporting empirical evidence for the key mechanism of the model. Section 6 concludes.

2 Model Economy

To study the relation between monetary policy and inequality, I develop a quantitative heterogeneous agent New Keynesian (HANK) economy. There are five building blocks of the model economy: a continuum (measure one) of heterogeneous households, the monetary authority, the government, a mutual fund, and firms.

2.1 Heterogeneity

I investigate the implications for monetary policy in the presence of substantial heterogeneity across characteristics of individual households, including wealth, income, employment, and consumption. To reproduce key features of the various distributions in the U.S. economy, I introduce two types of heterogeneity: households are heterogeneous in the time-discount factor and labor productivity. As in standard incomplete market literature, I assume that each evolves stochastically over time but is independent of aggregate shocks.

First, individual households are subject to idiosyncratic preference shocks. I assume that households' discount factors, β, are different across households. More precisely, β can take on two values, $\beta \in \mathbf{S}_\beta = \{\beta_L, \beta_H\}$, where $0 < \beta_L < \beta_H < 1$. For an individual household, β is assumed to follow a discrete-time two-state Markov chain with transition matrix, $\mathbf{Q}^\beta$, as in Gornemann et al. (2016). The probability of a transition from i to j is given by $\mathbf{Q}^\beta(i,j) \geq 0$, where $\sum_j \mathbf{Q}^\beta(i,j) = 1$ for each $i = L$ and H.

Second, households also face idiosyncratic labor productivity shocks, denoted by x.[9] Stochastic evolution of x is described by the transition matrix, $\mathbf{Q}^\mathbf{x}$. I assume that x can take on N_x values, i.e., $x \in \mathbf{S}_\mathbf{x} = \{x_1, x_2, ..., x_{N_x}\}$, and labor productivity follows an N_x-state first-order Markov process. Specifically, the transition probability from l to m is given by $\mathbf{Q}^\mathbf{x}(l,m) \geq 0$, where $\sum_m \mathbf{Q}^\mathbf{x}(l,m) = 1$ for each $l = 1, 2, ..., N_x$. Households cannot issue any assets contingent on their future idiosyncratic risks, β and x, which implies that the asset markets are incomplete as in Huggett (1993) and Aiyagari (1994).

heterogeneity for aggregate consumption and output dynamics.

[9] In this model, I do not allow for a permanent component of the dynamics of labor productivity. In the standard HANK model, introducing the permanent component may amplify or dampen the aggregate effect of a monetary policy shock. For example, Alves et al. (2020) find that households which earn low permanent income are largely exposed to aggregate income shocks, which leads to an amplification of the aggregate consumption response.

2.2 Households

Each household maximizes her expected lifetime utility over consumption, c_t, and hours of work, h_t, shown as:

$$\max \mathbb{E}_0 \left[\sum_{t=0}^{\infty} B_t \left(\log c_t - g(h_t) \right) \right]$$

$$\text{with } g(h_t) = \chi h_t$$

subject to

$$c_t + a_{t+1} = w_t x_t h_t + (1 + r_t^k) a_t, \tag{1}$$

and

$$a_{t+1} \geq \underline{a} \text{ and } h_t \in \left\{ 0, \overline{h} \right\},$$

where $\chi > 0$ is a parameter for disutility from working, and B_t describes the cumulative discounting between period 0 and period t, i.e., $B_t = \prod_{k=0}^{t} \beta_k$. Each household faces the budget constraints as in Equation 1, where w_t is the real wage rate for the efficiency unit of labor. A household can save or borrow by trading a claim for financial assets (a mutual fund), a_t, which yields the real rate of return, r_t^k. A household faces a borrowing constraint: the assets holding, a_{t+1}, cannot go below $\underline{a}$ at any time.

Importantly, I assume that a labor supply decision made by a household is indivisible (Chang and Kim, 2007): a household supplies a fixed number of hours ($h_t = \overline{h}$), or she does not work at all ($h_t = 0$). Accordingly, there are two employment statuses for each household: employment and non-employment. Define θ and Θ as the vectors of individual and aggregate state variables, respectively: $\theta \equiv (\beta, a, x)$ and $\Theta \equiv (\mu, v)$, where $\mu(\theta)$ is the type distribution of households,[10] and v is monetary policy shocks. The value function for an employed household, denoted by $V^E(\theta, \Theta)$, is defined as:

$$V^E(\theta, \Theta) = \max_{c,a'} \left\{ \log c - \chi \overline{h} + \beta \mathbb{E} \left[V(\theta', \Theta') \right] \right\}$$

subject to

$$c + a' = wx\bar{h} + (1 + r^k)a, \; a' \geq \underline{a},$$

$$\mu' = \Psi(\Theta), \text{ and } v' = \mathbb{T}(v),$$

[10]Denote $\mathcal{B}, \mathcal{A}$, and $\mathcal{X}$ for sets of all possible realizations of β, a, and x, respectively. Then, the measure $\mu(\beta, a, x)$ is defined over a σ-algebra of $\mathcal{B} \times \mathcal{A} \times \mathcal{X}$.

where Ψ and $\mathbb{T}$ denote a forecasting function for μ and the law of motion for monetary policy shocks, respectively. To simplify notation, time subindices are suppressed, and primes denote variables in the next period. The value function for a non-employed household, denoted by $V^N(\theta, \Theta)$, is defined as follows:

$$V^N(\theta, \Theta) = \max_{c,a'} \{\log c + \beta \mathbb{E}\left[V(\theta', \Theta')\right]\}$$

subject to

$$c + a' = (1 + r^k)a,\ a' \geq \underline{a},$$

$$\mu' = \Psi(\Theta), \text{ and } v' = \mathbb{T}(v).$$

Then, the employment decision, $h(\theta, \Theta)$, for a household is given by the following:

$$V(\theta, \Theta) = \max_{h \in \{0, \bar{h}\}} \left\{V^E(\theta, \Theta), V^N(\theta, \Theta)\right\}. \tag{2}$$

In the model economy with indivisible labor, household optimization means that a household is employed if the market wage rate, $w(\Theta)$, is equal to or larger than her reservation wage rate, $w^R(\theta, \Theta)$. Formally,

$$h(\theta, \Theta) = \begin{cases} \bar{h} & \text{if } w(\Theta) \geq w^R(\theta, \Theta) \\ 0 & \text{otherwise} \end{cases}. \tag{3}$$

Importantly, the reservation wage rate differs across households, depending on net wealth, the discount factor, and productivity. Intuitively, given the time discount factor, the reservation wage is a decreasing function of labor productivity, x, and an increasing function of asset holdings, a.[11] When the market wage changes, the employment responses will differ across households. For example, a non-employed household having a reservation wage, which is close to the market wage, is more likely to become employed in response to an increase in the market wages. This implies that the model economy endogenously generates different labor supply elasticities across households.

2.3 Mutual Fund

In the model economy, there is no portfolio choice by the individual households. Instead, there is a representative mutual fund that owns shares in aggregate equity of the firms (S_t) and risk-free bonds (B_t). For the latter, abstracting public-sector debt or cash in the economy, I employ the cashless limit assumption (Woodford, 1998; Gornemann et al., 2016): the nominal gross interest rate on risk-free bonds, R_t, is controlled by the central bank. Note that the households own the equities of the representative mutual fund. The budget constraint of the mutual fund is given by the following:

[11] I will discuss later a graphical representation for the reservation wage schedules across individual types.

$$q_t^S S_{t+1} + A_{t+1} + B_{t+1} = q_t^S S_t + (1 + r_t^k) A_t + \frac{R_{t-1}}{\Pi_t} B_t, \tag{4}$$

where q_t^S is the price of a firm equity share, A_t is the total amount invested by the households, and Π_t is the gross rate of inflation between $t-1$ and t.[12] The mutual fund optimally allocates its budget over S_t and B_t. This implies the following no-arbitrage relation:

$$\mathbb{E}_t \left[Q_{t,t+1} \frac{q_{t+1}^S}{q_t^S} \right] = \mathbb{E}_t \left[Q_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right], \tag{5}$$

where $Q_{t,t+1}$ is a stochastic discount factor between t and $t+1$, which will be discussed below.[13] The equilibrium bond holdings for the representative mutual fund are zero. Therefore, the realized rate of return of the mutual fund is given as: $r_t^k = q_t^S / q_{t-1}^S - 1$. Regarding the stochastic discount factor, it is not necessarily unique in incomplete asset markets economies. For tractability, I assume that the stochastic discount factor is driven by aggregate consumption (Ozkan et al., 2017; Sargent et al., 2017).[14] The stochastic discount factor between t and $t+\tau$, denoted by $Q_{t,t+\tau}$, is given by the following:

$$Q_{t,t+\tau} = \overline{\beta}^{\tau} \tfrac{u_c(C_{t+\tau})}{u_c(C_t)},$$

where $\tau \geq 0$, $\overline{\beta}$ is the average time discount factor, $u_c(\cdot)$ is the marginal utility of consumption, and C_t is aggregate consumption (i.e., $C_t = \int c_t(\theta_t, \Theta_t) d\mu_t$).[15]

2.4 Intermediate Goods Producers

There is a continuum of monopolistically competitive firms indexed by $j \in [0,1]$, each of which produces a different type of intermediate good $y_t(j)$. Each intermediate-goods monopolistic firm produces its differentiated good, j, following the Cobb-Douglas production function:

$$y_t(j) = k_t(j)^{\alpha} l_t(j)^{1-\alpha} - f,$$

where $k_t(j)$ is capital used, $l_t(j)$ is effective labor, α is the capital income share, and $f \geq 0$ is the fixed cost of production.[16] Capital depreciates at rate δ each period.[17] Since the firms face the same

[12] It is assumed that the government takes all dividends from the firms (this will be discussed in detail later). Accordingly, the dividend is not included in the budget constraint of the mutual fund.

[13] The aggregate firm equity share is normalized to unity.

[14] This assumption allows us to reduce a computational burden substantially relative to a case of using the weighted average of households' marginal utilities. Similarly, Gornemann et al. (2021) use a simple version of the stochastic discount factor to reduce a numerical burden.

[15] Note that, by construction, the average time discount factor, $\overline{\beta}$, is constant over time.

[16] The fixed cost will be set to ensure that profits are zero in the steady state.

[17] To keep the analysis simpler, I assume absence of investment or capital adjustment costs in the model economy. This assumption allows us to reduce a computational burden since there is no shadow price of capital and no additional state.

factor prices, the cost-minimization problem implies that they must all have the same capital–labor ratio and the real marginal cost, m_t:

$$\frac{k_t(j)}{l_t(j)} = \frac{\alpha}{1-\alpha}\frac{w_t}{r_t^k+\delta},$$

$$m_t = \Delta \left(r_t^k + \delta\right)^{\alpha} w_t^{1-\alpha},$$

where $\Delta = (1-\alpha)^{\alpha-1}\alpha^{-\alpha}$. There is nominal price stickiness in the economy. Price adjustment is subject to Rotemberg (1982)'s price setting mechanism: each intermediate goods firm, j, faces quadratic adjustment price costs. An intermediate goods firm, j, maximizes its expected discounted profit by choosing its price, $p_t(j)$:

$$\max_{p_{t+\tau}(j)} \mathbb{E}_t \left[\sum_{\tau=0}^{\infty} Q_{t,t+\tau} \left\{ \left(\frac{p_{t+\tau}(j)}{P_{t+\tau}} - m_{t+\tau}\right) y_{t+\tau}(j) - \frac{\Psi}{2}\left(\frac{p_{t+\tau}(j)}{p_{t+\tau-1}(j)} - \overline{\Pi}\right)^2 Y_{t+\tau} - T_t \right\}\right],$$

subject to

$$y_t(j) = \left(\frac{p_t(j)}{P_t}\right)^{-\epsilon} Y_t, \tag{6}$$

where $\tau \geq 0$; the parameter, $\Psi > 0$, is the extent of nominal rigidities; $\overline{\Pi}$ is the steady-state gross inflation; T_t is corporate lump-sum taxes; and $\epsilon > 1$ is the elasticity of substitution for intermediate goods. Equation 6 is the demand for intermediate good j, which is driven by the final good firm's optimization. The optimal behavior by intermediate goods firms and symmetric equilibrium conditions (i.e., $p_t(j) = P_t$ and $y_t(j) = Y_t$) lead to the following New Keynesian Phillips curve:

$$1 + \frac{\Psi}{\epsilon-1}\left(\Pi_t - \overline{\Pi}\right)\Pi_t - \frac{\epsilon}{\epsilon-1} m_t = \frac{\Psi}{\epsilon-1}\mathbb{E}_t\left[Q_{t,t+1}\left\{\Pi_{t+1} - \overline{\Pi}\right\}\Pi_{t+1}\frac{Y_{t+1}}{Y_t}\right].$$

2.5 Final Good Producer

There is a representative final good firm in a competitive sector. To produce a homogeneous output, Y_t, the final good firm assembles intermediate goods, according to the constant elasticity of substitution technology:

$$Y_t = \left(\int_0^1 y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}},$$

where $y_t(j)$ is the input of the jth intermediate input. The final good firm in this sector takes the final-goods price, P_t, as given and pays $p_t(j)$ for each of its inputs, where $p_t(j)$ is the price of the jth intermediate input. Cost minimization for the representative firm, together with the zero-profit condition, implies that the demand for intermediate good j is given as:

$$y_t(j) = \left(\frac{p_t(j)}{P_t}\right)^{-\epsilon} Y_t \quad \text{with } P_t = \left(\int_0^1 p_t(j)^{1-\epsilon} dj\right)^{\frac{1}{1-\epsilon}}.$$

2.6 Central Bank and Government

The central bank conducts monetary policy by setting the nominal interest on risk-free nominal bonds. The gross nominal interest rate, R_t, is assumed to follow the conventional Taylor rule:

$$\log R_t = \log \overline{R} + \phi_\pi \left(\log \Pi_t - \log \overline{\Pi} \right) + \phi_y \left(\log Y_t - \log \overline{Y} \right) + v_t, \tag{7}$$

where $\phi_\pi > 1$, $\phi_y \geq 0$, and $\overline{R}$, $\overline{\Pi}$, and $\overline{Y}$ are the deterministic steady-state values of the corresponding variables. Monetary policy shocks, v_t, follow an AR(1) process:

$$v' = \rho_v v + \varepsilon_v', \quad \varepsilon_v' \sim N(0, {\sigma_v}^2).$$ [18]

In model economies of monopolistic competition with sticky prices only, markups are countercyclical, implying negative profits in response to an expansionary monetary policy shock. However, abundant empirical evidence suggests that profits are procyclical conditional on monetary policy (e.g., Christiano et al., 2005). The countercyclical markups or profits have counterfactual implications in the economy. If profits are equally distributed across households, then the fall in profits associated with an expansionary monetary shock creates a negative wealth effect, which dampens the consumption response and shifts the labor supply curve to the right. As discussed in Kaplan et al. (2018), if profits are distributed depending on the level of wealth, this will affect the volatility and cyclicality of investment: the countercyclical markups produce a downward pull on investment. To avoid these counterfactual implications of nominal price rigidities, I assume that profits, D_t, are taxed at a rate of 100 percent, and that the tax revenues, T_t, are used for wasteful government consumption:

$$D_t = T_t = G_t,$$

where G_t is government spending.[19] This means that households do not receive any profit income from intermediate-goods monopolistic firms, as in Equation 1. This assumption allows us to focus on the key mechanism of the model (the labor-supply channel), by eliminating the wealth effects associated with countercyclical profits on employment decisions of households.[20]

2.7 Definition of Equilibrium

A recursive competitive equilibrium is a set of value functions, $\{V^E(\theta,\Theta), V^N(\theta,\Theta), V(\theta,\Theta)\}$, a transition operator, $\Psi(\Theta)$, a set of policy functions, $\{c(\theta,\Theta), a'(\theta,\Theta), h(\theta,\Theta), k_j(\Theta), l_j(\Theta), p_j(\Theta), y_j(\Theta)\}$, and a set of prices, $\left\{w(\Theta), r^k(\Theta), R(\Theta), \mathit{\Pi}(\Theta)\right\}$, such that:

[18] I discretize the continuous AR(1) processes of monetary policy shocks as Markov chains, using the algorithm developed in Tauchen (1986).

[19] This means that government consumption is zero in the steady state.

[20] See Appendix for further discussion about how monetary transmission varies depending on the distribution of countercyclical profits.

1. Individual households' optimization: given $w(\Theta)$ and $r^k(\Theta)$, optimal decision rules $c(\theta,\Theta)$, $a'(\theta,\Theta)$, and $h(\theta,\Theta)$ solve the Bellman equation, $V(\theta,\Theta)$.

2. Intermediate goods firms' optimization: given $w(\Theta)$, $r^k(\Theta)$, $Q(\Theta,\Theta')$, and $P(\Theta)$, the associated optimal decision rules are $k_j(\Theta)$, $l_j(\Theta)$, and $p_j(\Theta)$.[21]

3. Final good firm's optimization: given a set of prices $P(\Theta)$ and $p_j(\Theta)$, the associated optimal decision rules are $y_j(\Theta)$ and $Y(\Theta)$.

4. The stochastic discount factor, $Q(\Theta,\Theta')$, satisfies $\mathbb{E}\left[Q(\Theta,\Theta')\frac{R(\Theta)}{\Pi(\Theta')}\right]=1$.

5. The gross nominal interest rate, $R(\Theta)$, satisfies the Taylor rule (Equation 7).

6. Balanced budget of the government: $D(\Theta)=T(\Theta)=G(\Theta)$.[22]

7. Market clearing: for all Θ,

   - labor market clearing: $L(\Theta)=\int xh(\theta,\Theta)d\mu$, where $L(\Theta)=\int l_j(\Theta)dj$
   - capital market clearing: $K(\Theta)=\int a d\mu$, where $K(\Theta)=\int k_j(\Theta)dj$
   - goods market clearing: $Y(\Theta)=C(\Theta)+I(\Theta)+G(\Theta)+\Xi(\Theta)$, where $Y(\Theta)=K(\Theta)^\alpha L(\Theta)^{1-\alpha}-f$, $C(\Theta)=\int c(\theta,\Theta)d\mu$, $I(\Theta)=K'(\Theta)-(1-\delta)K(\Theta)$, and $\Xi(\Theta)=\frac{\phi}{2}(\Pi(\Theta)-\overline{\Pi})^2Y(\Theta)$.

8. Law of motion for the aggregate capital: $K'(\Theta)=I(\Theta)+(1-\delta)K(\Theta)$.

9. Consistency of individual and aggregate behaviors: for all $B^0\subset\mathcal{B}$, $A^0\subset\mathcal{A}$, and $X^0\subset\mathcal{X}$,

$$\mu'(B^0,A^0,X^0)=\int_{B^0,A^0,X^0}\left\{\int_{\mathcal{B},\mathcal{A},\mathcal{X}}\mathbf{1}_{a'=a'(\theta,\Theta)}\mathbf{Q}^\beta(\beta,\beta')\mathbf{Q}^{\mathbf{x}}(x,x')d\mu\right\}da'd\beta'dx'.$$

3 Calibration

In this section, I discuss calibration for the parameters used in the model economy. A simulation period is a quarter in the model. Table 1 summarizes the parameter values used in the benchmark model.

3.1 Parameterization

3.1.1 Preference and Borrowing Constraint

According to the Michigan Time-Use Survey, a typical household spends around one third of her discretionary time for working. Hence, the fixed number of hours worked, $\overline{h}$, is chosen to be 1/3. The disutility parameter of working, χ, is set so that the employment rate is 70 percent, respectively.

Table 1: Parameters of the Model Economy

Parameter	Value	Description	Source/Target Moments
		Households	
β_H	0.98557	High time discount factor	See text
β_L	0.93629	Low time discount factor	See text
$\mathbf{Q}^\beta(H,H)$	0.9969	H to H transition Prob.	Gornemann et al. (2016)
$\overline{h}$	1/3	Extensive margin for hours worked	Michigan Time-Use Survey
χ	147.6	Disutility parameter	Employment rate
ρ_x	0.939	Persistence of x shocks	Chang et al. (2013)
σ_x	0.297	Standard deviation of x shocks	Earnings Gini
$\underline{a}$	-1.0	Borrowing limit	Kaplan et al. (2018)
		Firms	
α	0.33	Capital income share	Kaplan et al. (2018)
δ	0.025	Capital depreciation rate	Kydland and Prescott (1982)
f	0.119	Production fixed cost	Zero profit
ϵ	10	Elasticity of substitution	Kaplan et al. (2018)
Ψ	100	Price adjustment cost	Kaplan et al. (2018)
		Monetary Authority	
ϕ_π	1.5	Weight on inflation	Kormilitsina and Zubairy (2018)
ϕ_y	0.25	Weight on output	Kormilitsina and Zubairy (2018)
$\overline{\Pi}$	1.005	Steady state gross inflation	Gornemann et al. (2016)
$\overline{R}$	1.046	Steady state gross nom. interest	See text
ρ_v	0.7	Persistence of v shocks	Kormilitsina and Zubairy (2018)
$100 \times \sigma_v$	0.25	Standard deviation of v shocks	Kormilitsina and Zubairy (2018)

Following Kaplan et al. (2018), the borrowing limit, $\underline{a}$, is set to match the quarterly average income in the model economy.

3.1.2 Time Discount Factor

I discuss calibration of the parameters related to the heterogeneity in the time preference. I assume that households' discount factors, β, follow a two-state Markov process. I follow Gornemann et al. (2016) and assume that the transition matrix for β is symmetric, i.e., $\mathbf{Q}^\beta(H,H) = \mathbf{Q}^\beta(L,L)$ or $\mathbf{Q}^\beta(L,H) = \mathbf{Q}^\beta(H,L)$. This implies that each household has an equal probability of drawing each of the two in this event. Accordingly, there are three parameters to calibrate, which are associated with the stochastic time preference: β_L, β_H, and $\mathbf{Q}^\beta(H,H)$.[23] I parameterize β_H and β_L by ensuring that the model economy matches the wealth Gini index of 0.78, and the quarterly return to capital

[21] The rental rate of capital satisfies the intermediate goods firm's first-order condition: $r^k(\Theta)+\delta = \alpha m(\Theta)\left(\frac{l(j)}{k(j)}\right)^{1-\alpha}$.

[22] Note that $D(\Theta)$ is profits net of price adjustment costs, i.e., $D(\Theta) = Y(\Theta) - w(\Theta)L(\Theta) - (r^k(\Theta)+\delta)K(\Theta) - \frac{\phi}{2}(\Pi(\Theta) - \overline{\Pi})^2 Y(\Theta)$.

[23] Note that once $\mathbf{Q}^\beta(H,H)$ is determined, $\mathbf{Q}^\beta(H,L)$ can be obtained by the condition that $\mathbf{Q}^\beta(H,L) = 1 - \mathbf{Q}^\beta(H,H)$.

of one percent (4 percent annualized) in the steady state. As in Krusell and Smith (1998), I calibrate $\mathbf{Q}^{\beta}(H,H)$ to capture changes in the saving behavior between generations: I follow Gornemann et al. (2016) and choose $\mathbf{Q}^{\beta}(H,H)$ so that the average duration of discount factors is 40 years.

3.1.3 Labor Productivity Process

I calibrate parameters related to labor productivity, x, as follows. I determine individual labor productivity and the transition matrix by discretizing a log-normal process, $\ln x' = \rho_x \ln x + \varepsilon_x'$, $\varepsilon_x' \sim N(0, {\sigma_x}^2)$. I use 15 values of labor productivity ($N_x = 15$) and discretize the transition probability matrices, $\mathbf{Q^x}$, using the algorithm developed in Tauchen (1986). Following Chang et al. (2013), I set $\rho_x = 0.939$, which is estimated with the AR(1) wage process from the Panel Study of Income Dynamics (PSID).[24] Chang et al. (2013) estimate the parameter by controlling for observed characteristics.[25] Hence, ρ_x captures persistence of a wage residual, which is the part of an individual wage not explained by individual characteristics. To see whether the model generates empirically realistic wage dynamics, I follow Takahashi (2020) and compute the implied wage dynamics using the model-generated panel data with 10,000 individuals for 2,500 quarters (discarding the first 500 periods). The implied AR(1) coefficient in the model is 0.943, which is close to what is found in the data.[26]

The standard deviation of individual productivity shocks, σ_x, is closely related to earnings heterogeneity. Accordingly, I choose $\sigma_x = 0.297$ by ensuring that the steady-state earnings Gini coefficient is 0.63. This value of σ_x is comparable to the empirical estimate reported in Chang et al. (2013) ($\sigma_x = 0.287$). Given the choice of the standard deviation of individual earnings risks, it is also important to see if the model matches the earnings distribution among employed households in the data. The earnings Gini coefficient conditional on working in the model is 0.44, comparable to the 0.43 in the PSID 1992.

3.1.4 Production Technology

Parameter values for production are quite standard. The capital income share, α, and quarterly depreciation rate, δ, are chosen to be 0.33 and 2.5 percent, respectively. The production fixed cost, f, is set for intermediate goods firms to have zero profit in the steady state. The elasticity of substitution across intermediate goods ϵ is equal to 10, which implies that a steady-state markup is 11 percent (Kaplan et al., 2018). The parameter for the Rotemberg price adjustment, Ψ, is set to 100 (Kaplan et al., 2018), implying that firms, on average, update their price every 4 quarters given the choice of the elasticity of substitution.[27] The choice of the Calvo stickiness parameter is standard in the literature, but it implies a relatively strong response of inflation to a monetary shock.

[24] Takahashi (2020) also estimates the persistence parameter with the PSID and finds a similar number ($\rho_x = 0.930$).

[25] Chang et al. (2013) use the Heckman's maximum-likelihood estimation (MLE) to solve the self-selection problem for wage workers.

[26] The model-implied σ_x is 0.298, which is also similar to the calibrated value (0.297).

[27] Given a Calvo parameter, θ, the Rotemberg price adjustment cost parameter, ϕ, can be computed such that: $\phi = \frac{\theta(\epsilon-1)}{(1-\theta)(1-\overline{\beta}\theta)}$.

I consider different price stickiness parameters in the reasonable range and find that the main results are robust.

3.1.5 Monetary Policy

The Taylor rule coefficients of inflation and output, ϕ_π and ϕ_y, are chosen to be 1.5 and 0.25, respectively. Regarding the monetary policy shocks, I choose $\rho_v = 0.7$ and $\sigma_v = 0.0025$. These choices are conventional values in the New Keynesian DSGE literature and are consistent with the estimates in the empirical literature (e.g., Kormilitsina and Zubairy, 2018, among others). The steady-state gross inflation, $\overline{\Pi}$, is set to target an inflation rate of 2 percent annualized, and then the steady-state gross interest rate, $\overline{R}$, is chosen to satisfy Equation 5 in the steady state (i.e., $\overline{R} = \overline{\Pi}/\overline{\beta}$).[28]

3.2 Implications and Model Fit

In this subsection, I analyze whether the model economy produces empirically realistic inequalities and aggregate effects of monetary policy observed in the data.

3.2.1 Aggregate Effects of Monetary Policy

I first discuss the effects of an expansionary monetary policy shock on aggregate variables in the economy. The responses of key aggregate variables in the model economy to 100-basis-point (annualized) expansionary monetary policy shocks for a 20-quarter horizon are shown in Figure 1. The model economy inherits the typical feature in the context of standard New Keynesian models. That is, the key mechanism of effects of unexpected monetary easing on real economic activity in the model is the countercyclical markups. In response to an expansionary monetary policy shock, sticky prices cause the markups of intermediate goods firms to fall, which increases aggregate demand. The expending increases the demand for both labor and capital inputs and their prices, along with a rise in the real marginal cost, which allows households to work more and accumulate more assets. Therefore, output and investment rise by 0.3 percent and 4.0 percent, respectively. A fall in the real interest rate on risk-free bonds, combined with a rise in overall income, causes household consumption to increase by 0.18 percent on impact. Finally, a 100-basis-point (annualized) monetary expansion increases annualized inflation by 0.83 percentage points. The responses of most of the macro variables in this figure are well-supported by the empirical literature (e.g., Christiano et al., 2005).[29]

3.2.2 Cross-sectional Distributions

Next, I discuss whether the model economy produces reasonable heterogeneity across individual households. Panel (A) in Table 2 compares the Gini coefficients for income, earnings, net asset

[28] It should be noted that, given the condition, $\overline{R} = \overline{\Pi}/\overline{\beta}$, a choice of a set of $\overline{\Pi}$ and $\overline{R}$ does not affect the dynamics of the economy.

[29] Since there are no investment or capital adjustment costs in this model, the investment response is much larger than the empirical counterpart documented in Christiano et al. (2005).

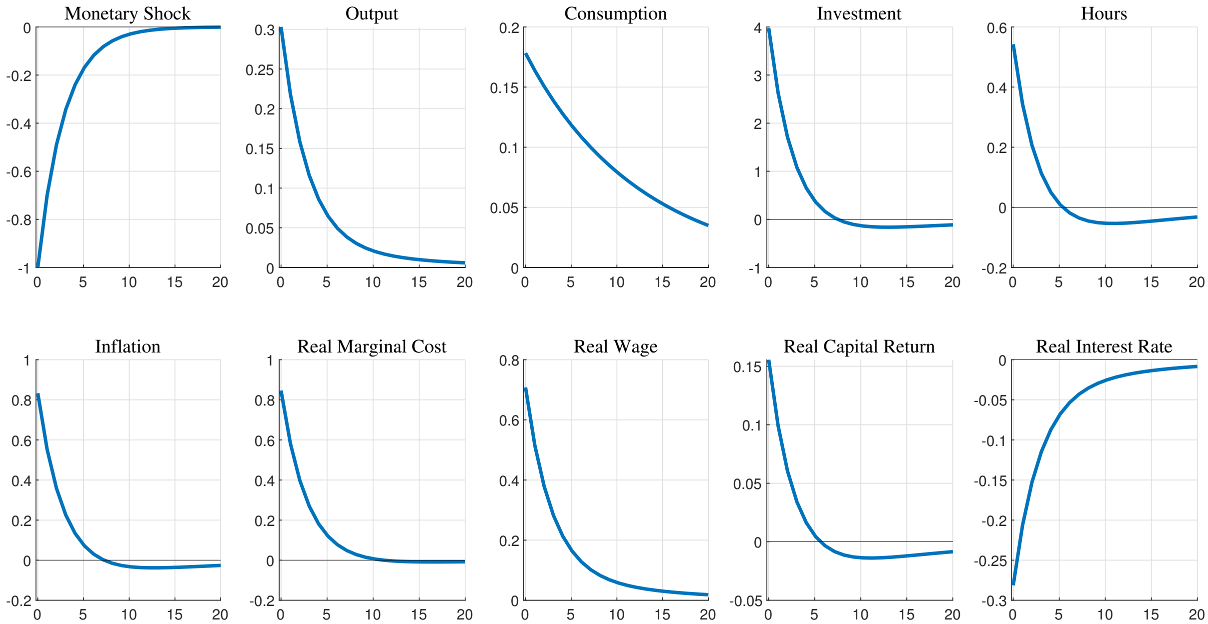

Figure 1: Impulse Responses of Aggregate Variables

Note: Impulse response to a 100-basis-point (annualized) monetary policy shock. For output, consumption, investment, hours, real marginal costs, and real wages, the y axis shows percent changes, while, for the remaining variables, the y axis shows changes in annualized percentage points. The x-axis shows quarters after the shock.

holdings, and consumption in the model to the U.S. data.[30] The benchmark model is successful in targeting the earnings and wealth distributions: the model economy makes the earnings and wealth Gini coefficients 0.63 and 0.78, respectively. The model economy also fits the untargeted distributions reasonably well. Consumption inequality is also well replicated: the Gini index for consumption is 0.37 in the model, which is similar to the U.S. data (0.33). Importantly, the model economy successfully reproduces the income distribution, which is a baseline dimension of inequality in this paper to study the disaggregate effects on monetary policy. The income Gini index in the model economy is exactly the same as that in the U.S. data (0.57). Panel (B) in Table 2 reports two characteristics of the income distribution in the data and the model economy. The model economy broadly replicates the transitory income shares across income groups, even if it produces an increasing pattern while they are a hump shape in the data.[31] Lastly, as shown in the data, the increasing pattern of the employment rates across the income quartiles is reasonably reproduced by the model economy. From the results found in Table 2, I argue that the model economy generates reasonable heterogeneity to study the distributional effects of monetary policy shocks.

4 Main Results

[30] I use the 1992 survey year for all data sources, because it falls in the midpoint of the sample period used for the empirical analysis in Section 4.3.

[31] Transitory income in the data is defined as labor income for salary workers and business income for self-employed workers, while it is defined as labor income in the model.

Table 2: KEY DISTRIBUTIONS

U.S. Data				
(A) Gini Index for	Income	Earnings	Wealth	Consum.
	0.57	0.63	0.78	0.33
(B) Characteristics of Income Distribution (ranked by income)				
Quartile	1st	2nd	3rd	4th
Share of Transitory Income	30.48	89.89	95.93	94.52
Employment Rate	22.07	73.42	89.94	94.32
Model Economy				
(A) Gini Index for	Income	Earnings	Wealth	Consum.
	0.57	0.63	0.78	0.37
(B) Characteristics of Income Distribution (ranked by income)				
Quartile	1st	2nd	3rd	4th
Share of Transitory Income	52.00	64.74	81.52	90.69
Employment Rate	31.18	63.09	85.89	99.02

Note: The Gini coefficients for income, earnings, and wealth in the data are from the 1992 Survey of Consumer Finances (SCF) in Diaz-Gimenez et al. (1997), while the consumption Gini is from the 1992 Consumer Expenditures Survey (CEX). Employment rates and transitory income shares across the income groups are from the 1992 Current Population Survey (CPS). In the CPS, income is defined as the sum of labor, capital, and business income. In the model, earnings are defined as labor income, while income is defined as the sum of labor and capital income. Employment statuses in the data are determined based on whether the head of the household is employed. Transitory income in the data is defined as labor income for salary workers and business income for self-employed workers, while it is defined as labor income in the model.

4.1 The Distributional Effects of a Monetary Easing

In this subsection, I investigate the effects of monetary policy shocks on inequality, focusing on the impact on income distribution. I first discuss heterogeneity in labor supply elasticity across individual households and then investigate the transmission mechanism of the distributional effects of monetary policy.

4.1.1 Heterogeneity in Labor Supply Elasticity

I first discuss the reservation wage function generated by the model economy to have better understanding of the labor supply decisions for households, which is the key mechanism for the distributional consequences of monetary policy. Figure 2 displays the reservation wage (per effective labor) schedules over net wealth and productivity in the steady state for patient households, i.e., $w^R(\beta_H, a, x)$. As briefly discussed earlier, the reservation wage differs across the type of households: it is an increasing function of net asset holdings, but is a decreasing function of labor productivity. From this figure, we can draw two implications.[32] First, as discussed in Chang and Kim (2006), macro labor supply elasticity is endogenously generated in this economy, depending on the mass of "marginal workers", whose reservation wages are close to the market wage. Second, individual-level

[32]The same logic can be applied to the reservation wage schedules for impatient households, $w^R(\beta_L, a, x)$. I do not report them here since they have a very similar shape to that of $w^R(\beta_H, a, x)$ from a qualitative perspective.

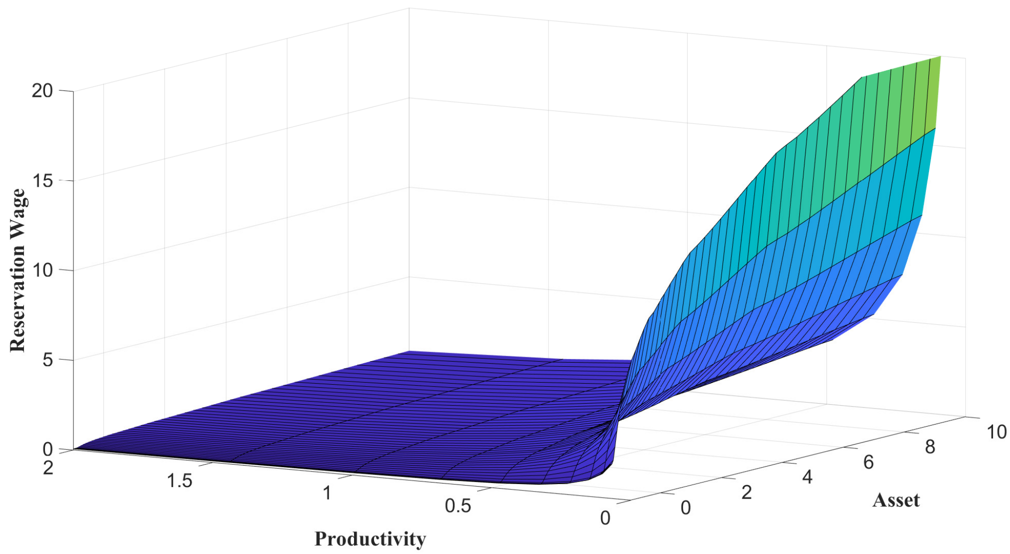

Figure 2: Reservation Wage Schedule over Productivity and Assets
Note: The figure shows the model-implied reservation wage (per effective labor) schedules over productivity and assets for patient households ($\beta = \beta_H$).

labor supply elasticities are also different across households, implying that there are substantially heterogeneous employment responses to monetary policy shocks. For example, households whose reservation wages were slightly above the market wage are likely to be newly-employed in response to an expansionary monetary policy shock. Since the reservation wage is a decreasing function of productivity, households with relatively low productivity will be mostly affected by changes in monetary policy actions.

I estimate the model-implied elasticity based on running a standard labor supply regression with an artificial data from the model economy. As is standard in the empirical labor supply literature, I run the following regression:

$$\log h_t = b_0 + b_1 \log w_t + b_2 \log c_t + \varepsilon_t. \tag{8}$$

where is h_t is hours worked (or employment). The resulting parameter estimate, b_1, is the labor supply elasticity. As is known from the literature, the tightened link between preference parameter and implied labor supply elasticity will be broken by a modification of the standard labor supply model with a non-linear budget constraint (see, e.g., Rogerson and Wallenius, 2009, Chang and Kim, 2006).

Table 3 shows model-implied aggregate labor supply elasticity and the disaggregate labor supply elasticities across the income distribution.[33] As mentioned above, aggregate and disaggregate labor

[33] In general, the regression of labor supply on wages at the individual level generates selection bias. To address this issue, I run the regression with the group-level data: I compute the average hours, wages, and consumption for each income quartile and use them for the estimation.

Table 3: Aggregate and Disaggregate Labor Supply Elasticities

Income Quartile				Aggregate
1st	2nd	3rd	4th	
4.79	1.27	0.94	0.02	1.01

Note: All estimates are based on the OLS of Equation 8 using model-generated data (the quarterly time series of 2,000 periods). The income-quartile-level data are used for the regression. Income is defined as the sum of labor and capital income in the model.

supply elasticities are endogenously generated in the economy. The Ordinary Least Squares (OLS) estimate of b_1 based on aggregate time series, generated by monetary policy shocks, is 1.01. This value is larger than the aggregate labor supply elasticity of 0.86 implied by the steady-state labor supply curve, which will be discussed in Section 5. This suggests that, as found in Chang and Kim (2006), there is an estimation bias due to the failure of the aggregation theorem or due to the correlation between changes in aggregate labor demand and supply.[34]

An important finding in this section is that households have different labor supply elasticities across the income distribution. As is already implied by the reservation wage schedule shown in Figure 2, labor supply elasticity is decreasing over the level of income, since labor income associated with productivity is the main source of total income, by construction.[35] The OLS estimate of the elasticity for the first income quartile is 4.79, but almost zero for the income-richest. Considerable heterogeneity in labor supply elasticities across the income distribution implies that monetary policy can have substantially different effects on households' employment, thereby affecting the income distribution.

4.1.2 Effect of Monetary Policy on Inequality

One of the main focuses of this study is on the distributional effects of monetary policy shocks. Figure 3 depicts the effects of 100-basis-point (annualized) expansionary monetary policy shocks on Gini coefficients of income, earnings,[36] wealth, and consumption.[37] A monetary expansion, indeed, decreases overall inequality in the economy, as suggested by empirical literature such as Coibion et al. (2017), Mumtaz and Theophilopoulou (2017), and Furceri et al. (2018). The response of the consumption Gini coefficient is relatively small due to consumption-smoothing behaviors of the households. Since wealth is a state variable, it does not respond immediately, but its inequality decreases slowly after a monetary policy shock: the Gini coefficient of wealth falls by 0.03 percent by 6 quarters after the shock.

[34] Chang and Kim (2006) also find that the OLS estimate of labor supply elasticity based on model-generated aggregate time series is larger than that implied by the steady-state reservation-wage distribution.

[35] It should be noted that transitions between income quartiles are allowed, so they may affect the estimates of b_1.

[36] Earnings are defined as labor income of households.

[37] It should be noted that in a sticky-price version of New Keynesian framework with indivisible labor, any exogenous shocks (e.g., government spending shocks) that increase the demand for labor would achieve the same result of a decrease in the income equality. Similarly, even in a flexible-price economy with indivisible labor, an aggregate productivity shock also produces the result of decreased income Gini.

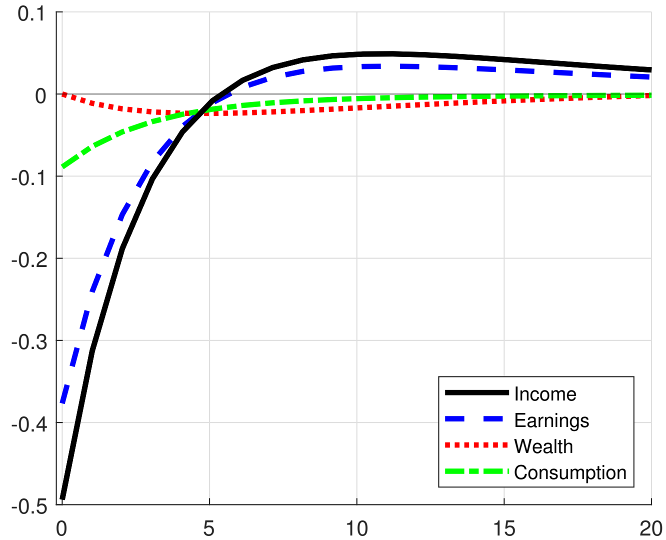

Figure 3: THE EFFECTS OF MONETARY POLICY ON GINI COEFFICIENTS
Note: The figure depicts the effects of one-standard-deviation expansionary monetary policy shocks on Gini coefficients of income, earnings, wealth, and consumption. The Gini coefficients are logged, so the responses are percentage deviations from the steady state.

This paper focuses on the transmission channel through which an unanticipated monetary easing affects income inequality. As discussed in literature, there are many possible channels of the distributional effects of monetary policy (see, for example, Coibion et al., 2017 and Auclert, 2019). In this paper, I propose a new channel for the effects of monetary policy on the income distribution. As found in Figure 3, monetary policy actions affect the income distribution considerably: the income Gini coefficient falls by 0.5 percent following a monetary expansion. The main mechanism of the effects of a monetary policy shock on the income distribution is through heterogeneity in the elasticity of labor supply across households. Due to nominal rigidities, an expansionary monetary policy shock reduces the markups of intermediate goods firms, which leads them to hire more workers in response to an increase in aggregate demand. At this stage of the analysis, an important question naturally arises: who will be newly-employed? As discussed in Figure 2, non-employed households, whose reservation wages are close to the market wage, tend to be additionally hired by the firms. This implies that less productive households tend to become newly employed. Since labor income, which is associated with productivity, is the main source of total income, employment is likely to rise at the bottom of income distributions. One can interpret this result through the lens of labor supply elasticity. In response to an increase in the market wage following a monetary expansion, households from the bottom of income distributions increase hours worked significantly, since their labor supply is relatively elastic, as shown in Table 3.

The rise in employment of the income-poor households substantially increases their labor income, thereby reducing income inequality. Figure 4, which compares the responses of employment rates and relative earnings across income quartiles in the model economy, confirms this.[38] As the left panel of Figure 4 reveals, income-poor households tend to become newly-employed following a monetary

[38]Relative earnings are defined as average labor income of each group divided by average labor income in the economy.

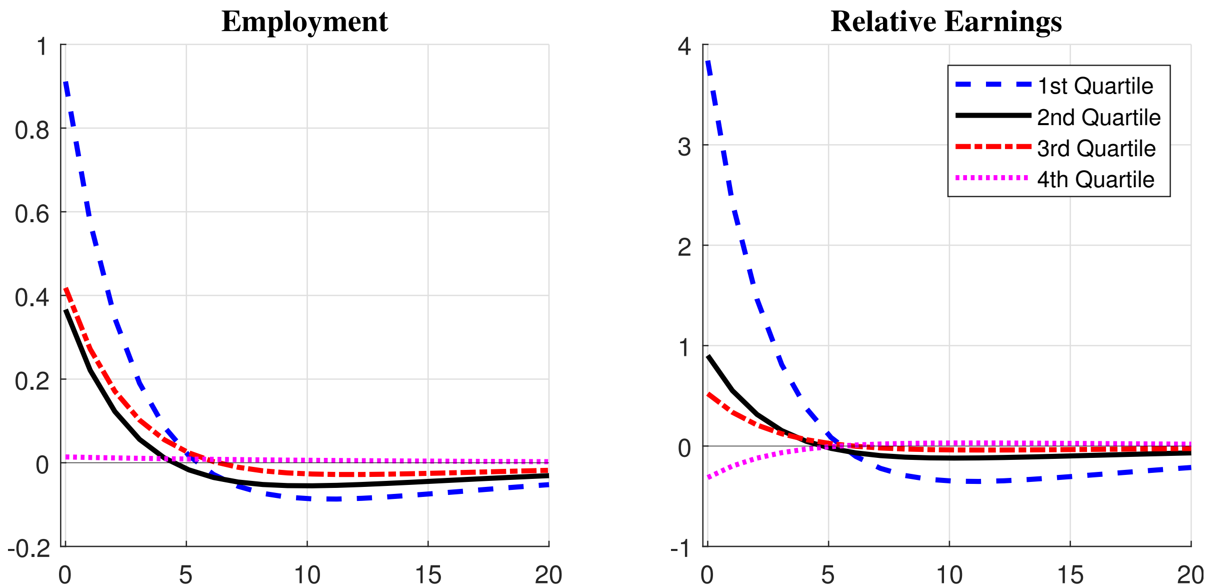

Figure 4: Responses of Relative Earnings and Hours

Note: The panels show responses of employment (the left panel) and relative earnings (the right panel) across income distribution in the model. Earnings are defined as labor income, while income is defined as the sum of labor and capital income in the model. Relative earnings are defined as average labor income of each group divided by average labor income in the economy. The responses in the left panel are percentage-point deviations from the steady state, and the responses in the right panel are percentage deviations from the steady state. The x-axis shows quarters after the shock.

expansion, while changes in employment are relatively small for the rich households: employment rates in the first income quartile increase by around 0.9 percent points, whereas households in the fourth quartile show no change. The substantially-increased employment from the bottom of the income distribution leads to a fall in income inequality. As shown in the right panel of Figure 4, the relative earnings for the poor increases while the rich lose their earnings in a relative sense, which makes the income and earnings Gini coefficients decrease on impact (Figure 3).[39]

Another interesting implication of the distributional effects of monetary policy is from decomposition of changes in earnings. Monetary policy shocks result in asymmetric effects on earnings, depending on relative responses of employment and wages. A rise in the market wage following a monetary expansion increases both employment and earnings per employment. To better elucidate how monetary policy shocks have compositional impacts on earnings, I further split the responses of the earnings across the income distribution into two elements: changes in employment (or hours) and average earnings (or earnings per employment). Figure 5 separates the responses of the total earnings into employment and average earnings across the income quartiles in the model economy. As shown in Figure 5, the increased total labor income for the poor is mainly due to a huge rise in employment. For example, employment responses account for around 50 percent of an increase in earnings on impact for households in the first income quartile, but almost zero percent for the fourth income quartile. Instead, the earnings responses for income-rich households are mostly explained by changes in average earnings. Therefore, there are compositional effects of monetary policy on

[39]There is a literature on the incidence of recessions showing that business cycles affect low productivity households more. This evidence gives additional support for the mechanism of this paper. See, e.g., Guvenen et al. (2017) and Patterson (2020).

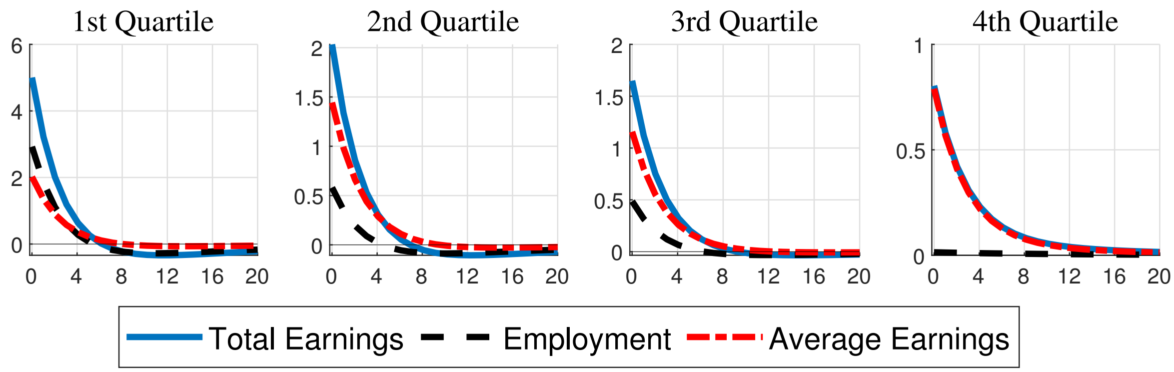

Figure 5: Decomposition of Earnings Responses: Model

Note: The graphs show percentage changes in total earnings, employment, and average earnings to expansionary monetary policy shocks in the model economy. Earnings are defined as labor income, while income is defined as the sum of labor and capital income in the model. The x-axis shows quarters after the shock.

earnings across the income distribution: the poor benefit from an increase in employment, whereas the rich benefit from a rise in average earnings in a relative sense.

4.1.3 Welfare Implications

Figure 6 shows the on-impact responses of consumption, hours (or employment), and welfare across productivity quartiles.[40] To see a relative effect, the average response for each variable is normalized at unity.[41] First, as discussed above (Figure 4 or Table 3), households with low productivity increase hours much more than productive households. Second, less productive households tend to increase their consumption more than productive households. Interestingly, there is smaller heterogeneity in the consumption responses across productivity quartiles, in line with the aforementioned finding that monetary policy has a smaller effect on the consumption Gini coefficient than on income or earnings Gini coefficients.

The relatively large consumption and hours responses of households with low productivity imply that the welfare implications may not be clear. Indeed, as shown in Figure 6, the welfare effect is non-linear across the productivity distribution. For example, despite the similar consumption responses, households in the second quartile have much smaller welfare gains than those in the first. This is mainly because households in the second quartile work much more than those in the first.[42] Importantly, it is productive households that have the bigger welfare gains from an unanticipated monetary easing. This is partly because the response of hours is relatively small for them (e.g., the fourth quartile). Besides, an insurance channel through wealth seems to play an important role in the welfare effect on productive households. In this model, productive households tend to hold a relatively large amount of assets, which can be used to hedge against consumption fluctuations. For instance, despite the similar hours responses, households in the third quartile enjoy a much greater

[40] It should be noted that the individual-level welfare effect can be computed by individual state variables such as productivity, the discount factor, and asset, but not by endogenous variables such as income. Accordingly, for this analysis, I use productivity quartiles instead of income quartiles.

[41] Following Gornemann et al. (2016), the welfare effects are measured as long-run consumption equivalents.

[42] Or, marginal workers are many in the second group.

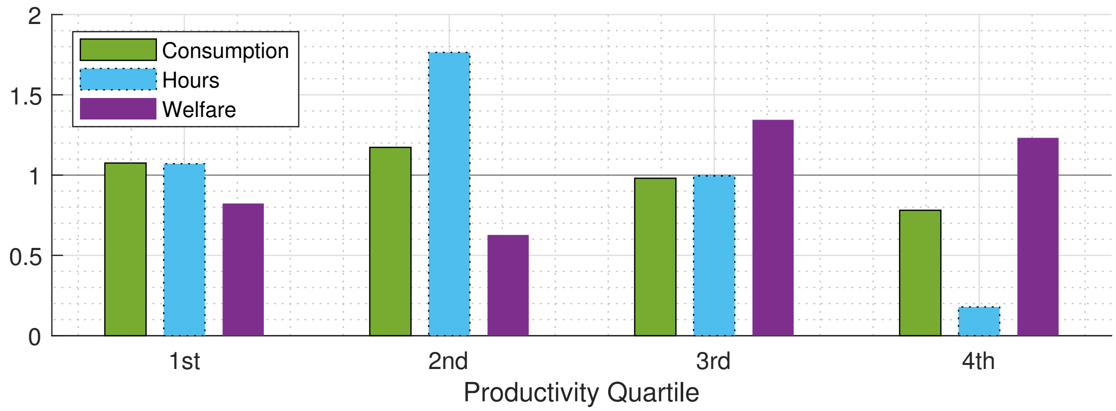

Figure 6: Heterogeneous Welfare Consequences of Monetary Policy

Note: The graphs show the on-impact responses of consumption, hours, and consumption-equivalent welfare across productivity quartiles. The average response for each variable is normalized at unity.

welfare effect than those in the first.

4.2 How Inequality Shapes Monetary Effectiveness

Next, I turn to the other main contribution of this paper. How does the long-run level of income inequality affect the effectiveness of monetary policy, and what is the linkage? To give a concrete answer to this question, I will take two steps. I first discuss how the long-run level of inequality determines the labor supply elasticity in the model economy. Then, I integrate a causal relation between the long-run level of inequality and the effectiveness of monetary policy by using labor supply elasticity as the main linkage for the relationship.

4.2.1 Inequality and Labor Supply Elasticity

A reservation wage for each household can be computed under the indivisible labor supply assumption in a heterogeneous-agent model, and its distribution determines aggregate labor supply elasticity in the economy. There is a tight link between inequality and labor supply elasticity in this economy. Since a degree of heterogeneity in the economy affects the shape of the reservation-wage schedule, degree of heterogeneity matters for the macro labor supply elasticity, as found in Chang and Kim (2006) and Rogerson and Wallenius (2009). Intuitively, less heterogeneity is associated with greater labor supply elasticity, since the reservation wage distribution is more concentrated, which implies that there are more marginal workers placed around the market wage.

To investigate the role on heterogeneity in aggregate labor supply elasticity, I consider a counterfactual economy with low inequality. I adjust the standard deviation of labor productivity, σ_x, to make the income Gini index around 10 percent less than that in the benchmark economy.[43] More in detail, σ_x is set to 0.208 for the model economy with less heterogeneity, causing the Gini coeffi-

[43] Cingano (2014) shows that the income Gini index in the U.K. is around 10 percent lower than that in the U.S. Thus, one may think this is a comparison between the U.S. (the benchmark) and the U.K. (the economy with lower inequality).

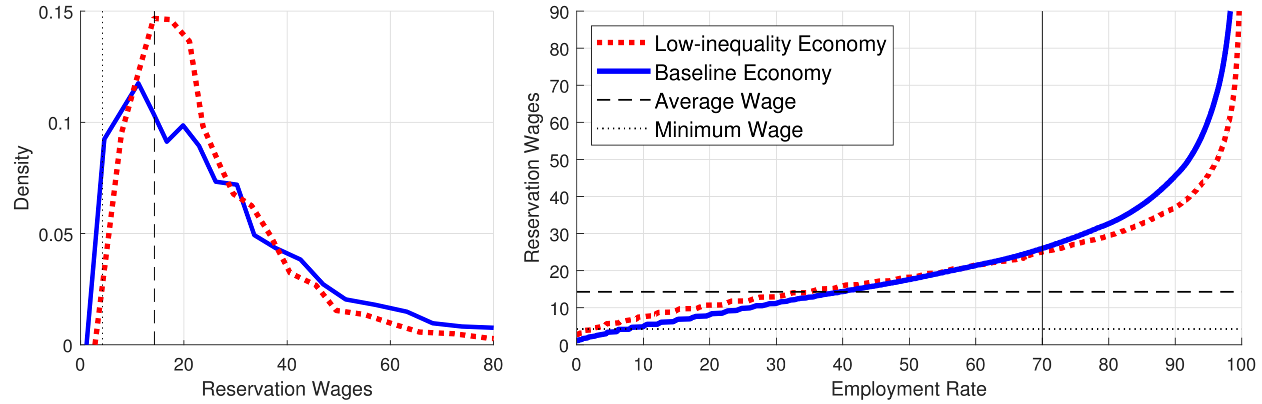

Figure 7: LABOR SUPPLY CURVES WITH DIFFERENT HETEROGENEITY

Note: The left figure shows distributions of reservation wages, and the right figure shows the inverse cumulative distributions of reservation wages with corresponding employment rates. The solid lines represent the benchmark economy ($\sigma_x = 0.297$) while the dotted lines show a counterfactual economy with low inequality ($\sigma_x = 0.209$).

cients for income and wealth reduce to 0.50 and 0.77, respectively. The reservation wage schedule and invariant distribution across households uncover the aggregate labor supply curve of the economy. The left panel in Figure 7 plots distributions of reservation wages for the benchmark economy ($\sigma_x = 0.297$) and the counterfactual economy with low inequality ($\sigma_x = 0.209$), where the mean wages (the dashed line) in both economies are normalized at the average hourly earnings in the PSID 1992 (14.29 dollars). It would be instructive to see whether the distribution of reservation wages in the benchmark model is empirically realistic. The fraction of households whose hourly earnings are equal to or less than the minimum wage (4.25 dollars, the dotted line) in the benchmark model is around 11.3 percent, which is comparable to the 11.9 percent in the PSID 1992.

An important finding is that the reservation wage distribution is more concentrated in the low-inequality economy: the density at the mean wage rate or the market wage rate in the low-inequality economy is greater than that in the benchmark economy. In other words, there are more marginal workers around the average wage or the market wage in the low-inequality economy. This implies that labor supply is more elastic for the economy with low inequality.

In the right panel of Figure 7, I report the inverse cumulative distributions of reservation wages with corresponding participation rates for the two different model economies. These inverse cumulative distributions represent nothing but the labor supply curves of the economies in the steady state. Based on these labor supply curves, the responsiveness of labor market participation can be computed. I calculate the elasticity at employment rates of 70 percent, which is the steady-state employment rate in both economies. As found in the existing literature (e.g., Chang and Kim, 2006), labor supply is more elastic for an economy with a smaller heterogeneity, since the reservation wage distribution is less dispersed. For the benchmark economy, aggregate labor supply elasticity is 0.86 at the steady-state employment rate, but 1.12 in the economy with a smaller degree of heterogeneity. As a result, a more equal economy has a greater labor supply elasticity, which will be the key linkage between the long-run level of inequality and the effectiveness of monetary policy.

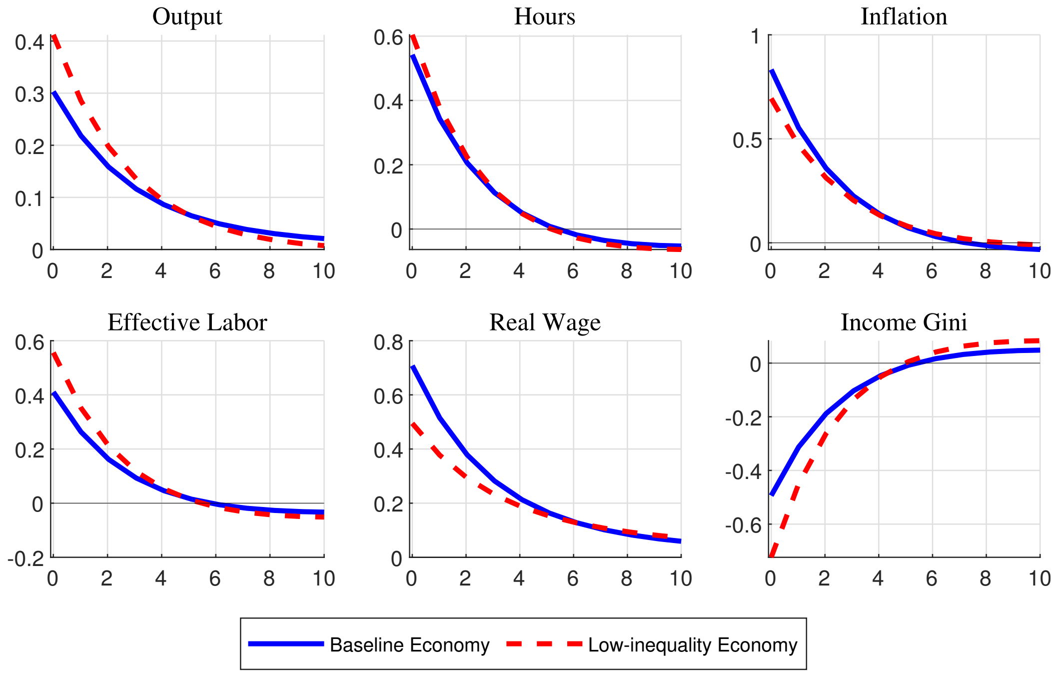

Figure 8: Responses of Key Variables with Different Heterogeneity
Note: The figure shows the responses of key aggregate variables to expansionary monetary policy shocks. The solid and the dotted lines represent the benchmark economy ($\sigma_x = 0.297$) and a counterfactual economy with low inequality ($\sigma_x = 0.209$), respectively. The x-axis shows quarters after the shock.

4.2.2 Impact of Inequality on Monetary Policy Effectiveness

Next, I investigate the role of long-run level of inequality in the effectiveness of monetary policy. Figure 8 shows the responses of key aggregate variables of two model economies (where $\sigma_x = 0.297$ and $\sigma_x = 0.209$) to monetary policy shocks. As expected, the long-run level of inequality matters for the effectiveness of monetary policy. According to Figure 8, a more equal society is associated with more effective monetary policy in terms of output, *ceteris paribus*. Output increases more in the model economy with less heterogeneity than that in the benchmark case: GDP increases by around 0.41 percent in the low-inequality economy, while it rises by 0.3 percent in the benchmark counterpart. As already noted, the main mechanism of the larger effectiveness comes from the labor supply elasticity, which represents the shape of reservation wage distribution. Since labor supply is more elastic in the low-inequality economy, the response of hours is larger than that in the benchmark economy, even if the response of real wages is much smaller in the more equal economy. Aggregate hours rise by 0.59 percent in the low-inequality economy, whereas total hours increase by 0.54 percent in the benchmark economy.[44]

The long-run level of inequality matters for the distributional effect of monetary policy as well. As found in Figure 8, the response of income Gini is larger in the low-inequality economy than that in the benchmark counterpart: the income Gini index decreases by 0.72 percent in the more equal society, but falls by 0.5 percent in the benchmark model. Greater heterogeneity in labor supply

[44] Marginal workers in the low-inequality economy are relatively homogeneous—the productivity difference between them is relatively small. Accordingly, the response of effective labor is also relatively large in the low-inequality economy.

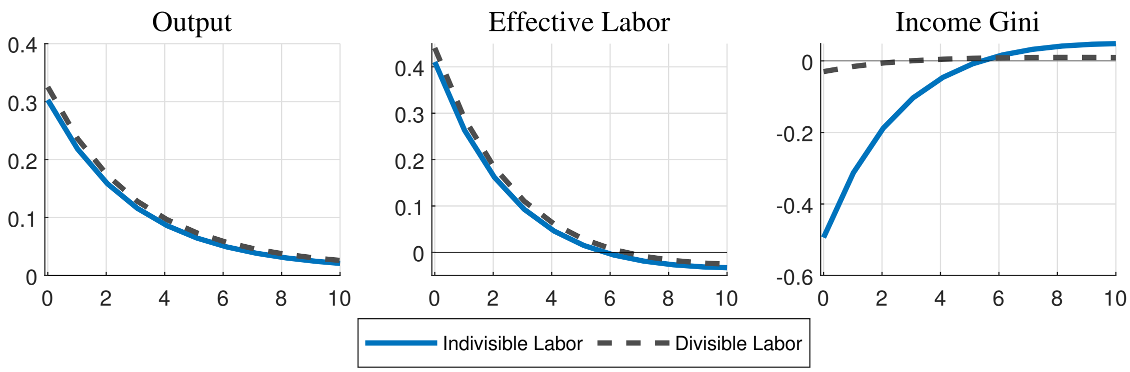

Figure 9: Indivisible vs. Divisible Labor Models

Note: The figure shows the responses of key aggregate variables of indivisible and divisible labor model economies. The solid lines represent the benchmark economy, while the dashed line shows the counterfactual economy with divisible-labor, in which $\gamma = 1.01$. The x-axis shows quarters after the shock.

elasticity across households in the more equal economy decreases income inequality to a greater degree following a monetary expansion. In more detail, in the low-inequality economy, households in the bottom of the income distribution have much higher labor supply elasticity than those in the baseline economy, while the elasticity of income-richest households is still almost zero in both economies. This implies that in the low-inequality economy, employment rises by more at the bottom of the income distribution, causing income inequality to fall by more.

To sum up, differences in heterogeneity generate differences in macro labor supply elasticity, which ultimately affects the effectiveness of monetary policy. *Ceteris paribus*, a more equal economy has a greater effectiveness of monetary policy in terms of output responses.

4.3 Clarifying the Mechanism

4.3.1 Role of Indivisible Labor

I discuss the role of indivisible labor supply in the distributional consequence of monetary policy. To investigate the marginal contribution of the indivisible labor assumption, I consider a counterfactual economy with divisible labor in which labor supply elasticity is given as a parameter, γ, i.e., $g(h) = \chi \frac{h^{1+1/\gamma}}{1+1/\gamma}$. By construction, the elasticity is the same between the poor and the rich in the divisible-labor economy.

Figure 9 compares the responses of key aggregate variables to a monetary expansion in the indivisible and divisible labor models, designated IL and DL models, respectively. By comparing these two economies, we can see the role of a discrete labor choice in the effects of monetary policy on the aggregate performance of the economy, and particularly on income inequality. For the DL model economy, I consider a counterfactual economy, where $\gamma = 1.01$, which is the benchmark estimate of the elasticity based on aggregate data generated by the IL model (Table 3).[45] As far as the aggregate effects are concerned, the response of aggregate effective labor is larger in the DL model

[45]It should be noted that the main results are very similar for the DL model where $\gamma = 0.86$, which is the aggregate labor supply elasticity implied by the steady-state labor supply curve in the IL model.

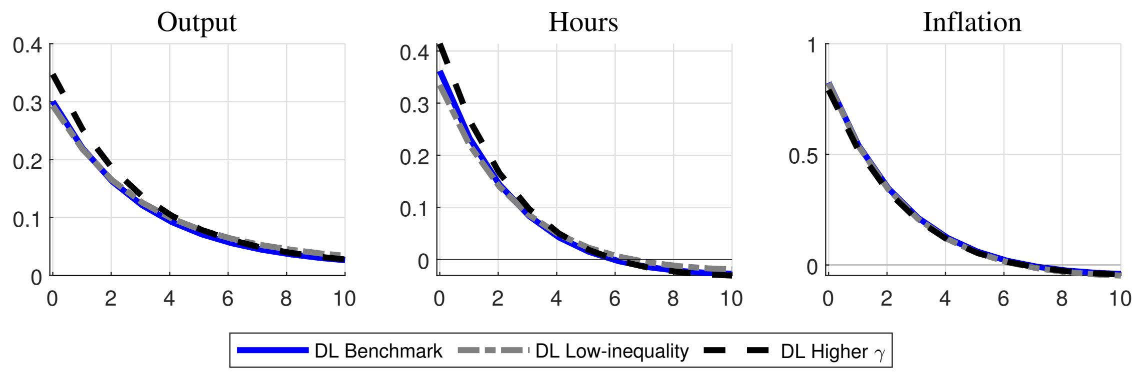

Figure 10: Responses of Key Variables with Different Heterogeneity

Note: The figure shows the responses of key aggregate variables to expansionary monetary policy shocks. "DL Benchmark" refers to a divisible labor model with benchmark heterogeneity ($\sigma_x = 0.297$) and labor supply elasticity ($\gamma = 0.86$); "DL Low-inequality" refers to a divisible labor supply with smaller heterogeneity ($\sigma_x = 0.209$), keeping the labor supply elasticity the same; "DL Higher γ" refers to a divisible labor model with larger labor supply elasticity ($\gamma = 1.12$) with the benchmark heterogeneity. The x-axis shows quarters after the shock.

(0.44 percent increase) than that in the IL model (0.41 percent increase). This is because productive households in the DL model have relatively high elasticity of labor supply compared to those in the IL model.[46] Accordingly, the DL model generates larger output response given the aggregate labor supply elasticity similar (ideally, identical) to that in the IL model: output rises by 0.33 percent on impact in the DL model, while the output response is 0.3 percent in the IL model.

An important finding is that the income Gini coefficient in the DL model does not decrease by as much as in the IL counterpart in response to a monetary expansion. The Gini coefficient for income falls by around 0.03 percent in the DL model, which is much smaller than the 0.5 percent in the IL model. This is because the homogeneous elasticity of labor supply in the DL models leads households to have similar hours responses across income distributions. The empirical finding discussed above shows that monetary policy shocks have a large effect on income inequality. Therefore, from a quantitative perspective, the indivisible labor supply plays an important part in producing the empirically-elastic response of the income Gini coefficient to monetary policy shocks.

What is the role of the indivisible labor in the different output responses to monetary policy shocks across different degrees of heterogeneity? As mentioned earlier, there is a tight relation between inequality and labor supply elasticity in a heterogeneous-agent model with a discrete labor choice, since a degree of heterogeneity affects the elasticity of labor supply. However, in divisible labor models, the long-run level of heterogeneity and labor supply elasticity are independent of each other, since both a degree of heterogeneity and labor supply elasticity are exogenously given as parameters, σ_x and γ, respectively.

To investigate the marginal contributions of indivisible labor supply, I consider three additional divisible labor model economies. The first model under consideration allows for a divisible labor model with the benchmark heterogeneity ($\sigma_x = 0.297$) and labor supply elasticity ($\gamma = 0.86$); the second model allows for a divisible labor supply with a smaller heterogeneity ($\sigma_x = 0.209$), keeping

[46]For example, the model-implied labor supply elasticity for the fourth quartile in the DL model is around 0.8, but nearly zero in the IL model.

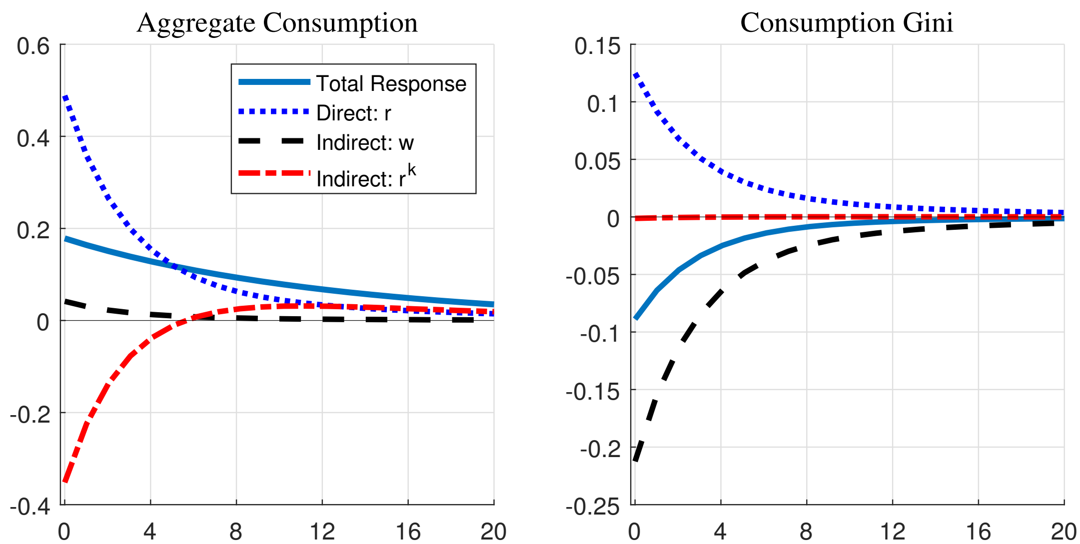

Figure 11: Direct and Indirect Effects on Consumption

Note: The figure shows the direct and indirect effects on aggregate consumption and the consumption Gini coefficient.

the labor supply elasticity the same; the third is a divisible labor model with a greater labor supply elasticity ($\gamma = 1.12$) with the benchmark heterogeneity. Accordingly, by comparing these three economies, I can analyze how important differences in degree of heterogeneity and labor supply elasticities are for the output responses in the model economies with divisible labor.

Figure 10 shows the responses of key aggregate variables for the three economies. As the divisible labor model with low inequality shows, a decrease in heterogeneity in a divisible labor model does not matter for the output response. The model with a smaller heterogeneity does not generate a different output response from that in the model with benchmark heterogeneity, since both have the same labor supply elasticity. This suggests that the discrete choice of labor supply plays a crucial role in connecting long-run inequality and the monetary policy effectiveness: a degree of heterogeneity matters for the real effect of monetary policy in indivisible labor models, but not in divisible models.

In contrast to a degree of heterogeneity, a size of aggregate labor supply matters for the output responses in the divisible labor models. In the divisible labor model with a higher labor supply elasticity ($\gamma = 1.12$), output and hours increase by more (0.35 and 0.42 percent, respectively), while the corresponding responses in the model with the benchmark elasticity ($\gamma = 0.86$) are 0.30 and 0.36 percent, respectively.

4.3.2 Direct vs. Indirect Effects on Consumption

I follow Kaplan et al. (2018) and decompose the effects of an expansionary monetary policy shock on consumption and its distribution into direct and indirect effects. The direct effect is an effect of changes in the real interest rate on risk-free bonds, and the indirect effects are channels that operate through changes in other prices (i.e., a general equilibrium effect), including real wages and the real rate of return on the mutual fund. The left panel in Figure 11 shows the direct and indirect effects of an expansionary monetary policy shock on aggregate consumption. Unlike in Kaplan et al. (2018), the aggregate consumption response is mostly due to the direct effect, and the indirect effect from changes in the real wage is very limited. This result is not surprising, because the current model does not allow for illiquid assets, so large indirect effects from hand-to-mouth households (or households with zero liquid wealth) are limited. The right panel in Figure 11 depicts the direct and indirect effects on the consumption Gini coefficient. An interesting finding emerges from this figure: the negative response of consumption Gini is mostly due to an indirect effect from changes in real wages. That is, households at the bottom increase consumption more than others since they work more in response to an increase in real wages. This finding is consistent with Figure 6.

4.3.3 Relation to Family Model

I consider a simple model with a family setting to discuss the effectiveness of monetary policy in the absence of market incompleteness, where the importance of endogenous wealth distribution is isolated. Suppose that firms produce differentiated goods using effective labor with a linear function, i.e., $y_t = l_t$. There is no capital in this economy. Prices are assumed to be sticky. Accordingly, the linearized New Keynesian Philips curve (NKPC) is:

$$\pi_t = \kappa \widetilde{m_t} + \beta E_t \pi_{t+1}$$

where π_t is inflation, $\widetilde{m_t}$ is the real marginal cost gap, and κ is a convolute parameter that basically captures how rigid prices are.[47] There is a unit mass of households, indexed by $i \in [0, 1]$. Preferences are the same as in the benchmark economy. Let $x(i)$ be a household's labor productivity, which is fixed over time. Households live in a family that provides perfect consumption insurance (i.e., complete asset markets). The family makes labor supply decisions for their members, by choosing a productivity cutoff, $\overline{x_t}$. This means that households that are more productive than this cutoff work, while others do not. Households can supply $\bar{h}$ hours or none. The production function implies the following:

$$y_t = \int_{\overline{x_t}}^{\infty} x \bar{h} \varphi(x) dx, \tag{9}$$

where $\varphi(x)$ is a probability density function for productivity. The optimal labor-supply decision implies the first-order condition:

$$c_t \chi = w_t \overline{x_t}. \tag{10}$$

In equilibrium, linearized Equations 9 and 10 imply the following:

$$\widetilde{w_t} = \left(1 + \frac{\varsigma}{\varphi(\overline{x})}\right) \widetilde{y}_t,$$

[47] Let $\widetilde{z}_t$ mark percent deviations of a variable z from its steady state at time t.

where $\varsigma = \frac{y}{\overline{x}^2}$. Since $\widetilde{mc}_t = \widetilde{w}_t$, the augmented NKPC is given:

$$\pi_t = \left(1 + \frac{\varsigma}{\varphi(\overline{x})}\right) \widetilde{y}_t + \beta E_t \pi_{t+1}. \tag{11}$$

According to Equation 11, the slope of the NKPC depends on the mass of marginal workers, $\varphi(\overline{x})$.[48] The more marginal workers there are, the flatter the NKPC is. The result found in the previous subsection can be interpreted as follows. There are more marginal workers in the low-inequality economy. Hence, it has a flatter NKPC, thereby generating the larger real effects of monetary policy shocks. As shown in Figure 8, the flatter NKPC in the low-inequality economy leads inflation to increase to a lesser degree than in the benchmark economy.

4.3.4 Skewness and Monetary Policy Effectiveness

It is also useful to discuss the relationship between skewness and the effectiveness of monetary policy. To do so, I use a truncated log normal distribution for labor productivity, keeping the parameters of the labor productivity shock process the same as in the benchmark case ($\rho_x = 0.939$ and $\sigma_x = 0.297$). Specifically, in the benchmark model, labor productivity follows a log normal distribution with the support of $[-3\sigma_{\hat{x}}, 3\sigma_{\hat{x}}]$, where $\sigma_{\hat{x}} = \sigma_x/\sqrt{1-\rho_x^2}$. For the economy with lower skewness, I use a distribution truncated from above at $1.7\sigma_{\hat{x}}$, i.e., the support is $[-3\sigma_{\hat{x}}, 1.7\sigma_{\hat{x}}]$. With this threshold, the income Gini index is 0.5, which is the same as that in the low-inequality economy with the smaller variance ($\sigma_x = 0.209$).

I find that the steady-state aggregate labor supply elasticity in the economy with lower skewness is 0.95, which is larger than that in the benchmark model (0.86). As expected, the effectiveness of monetary policy increases with lower skewness: a monetary expansion increases GDP by around 0.33 percent in the economy with lower skewness, which is larger than the output response in the benchmark counterpart (0.3 percent). Another interesting finding is that, given the same income Gini coefficient, the effect of a skewness change on the effectiveness of monetary policy is smaller than that of a change in variance. This is because the mass of marginal workers is less affected in the former case.

5 Empirical Evidence

5.1 Distributional Effects of Monetary Policy

In this subsection, I empirically document the distributional effects of monetary policy. Toward this end, I estimate the Vector Autoregressive (VAR) model using the Current Population Survey (CPS). In the CPS, annual income is defined as the sum of labor income, self-employment income, and net asset income before tax for all persons of a household. Earnings are defined as labor income for household members employed by someone and as self-employment income for self-employed workers.

[48] Of course, it also depends on the steady-state productivity of the marginal worker, $\overline{x}$.

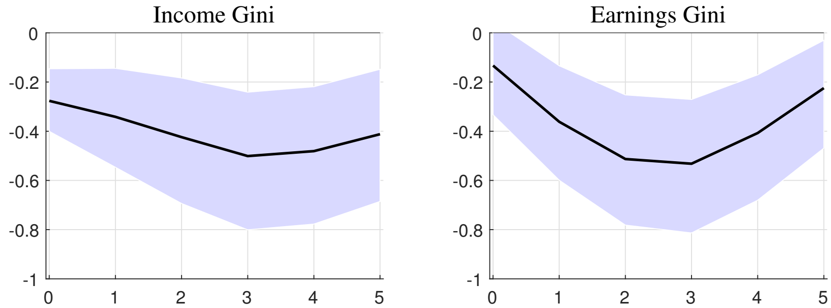

Figure 12: Response of Income and Earnings Distributions

Note: The figure presents the responses of Gini coefficients of income and earnings to an expansionary monetary policy shock. The y axis shows percentage changes, and the x-axis shows years after the shock. The shaded regions are the 68 percent confidence bands generated by Monte Carlo simulations.

For monetary policy shocks, I use measures developed by Romer and Romer (2004). Since information on income in the CPS is released in March of every year, I use annual data which span from 1969 to 2008. To estimate the effects of monetary policy shocks across the income distribution, I consider the following reduced-form VAR,

$$X_t = A(L)X_{t-1} + \eta_t, \tag{12}$$

where X_t is a vector including the measure for monetary policy shocks and a variable of interest; $A(L)$ is a polynomial in the lag operator; $\eta_t \sim N(0, \varSigma)$ are reduced-form innovations. The structural innovations, $\vartheta_t \sim N(0, I)$, are defined by an orthogonal rotation of the reduced-form residuals:

$$\vartheta_t = \Omega_0 \eta_t, \tag{13}$$

where $\Omega_0^{-1}(\Omega_0^{-1})' = \Sigma$. I order monetary policy shock measures first and other variable of interest is followed.[49] I identify the matrix Ω_0^{-1} as the Cholesky decomposition of Σ. Constant and trend terms are included in the VAR.[50]

Figure 13 depicts the effects of expansionary monetary policy shocks on Gini coefficients of income and earnings. Monetary policy actions have a considerable effect on the distributions of income and earnings: both Gini coefficients fall by around 0.5 percent following a monetary expansion.[51] These empirical findings are consistent with the model prediction from both qualitative and quantitative perspectives.

[49]As discussed in Anderson et al. (2016), by including the shocks measures in a VAR where the shock is ordered first, we can ensure that the shock is uncorrelated with past information contained in the other variables in the VAR, and that other variables respond to the shocks contemporaneously.

[50]The selection of lag lengths is based on both the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SIC).

[51]Mumtaz and Theophilopoulou (2017) and Furceri et al. (2018) also report that an unanticipated policy rate increase of 100 basis increases the income Gini index by around 0.5 percent.

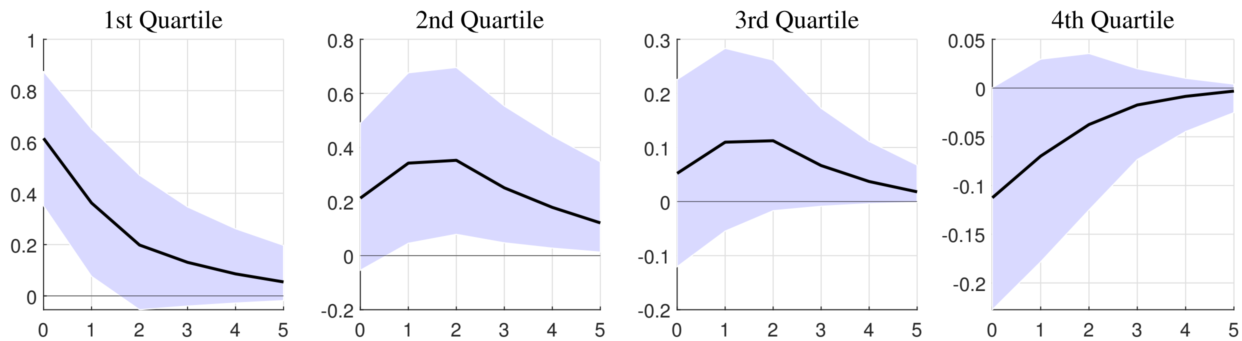

Figure 13: Response of Employment across Income Quartile

Note: The figure presents the responses of employment across different income quartiles to an expansionary monetary policy shock. Income in the data is defined as the sum of labor, capital, and business income. The y axis shows changes in percentage points, and the x-axis shows years after the shock. The shaded regions are the 68 percent confidence bands generated by Monte Carlo simulations.

Next, I provide suggestive empirical evidence for the different responses of employment across income groups to monetary policy shocks, which is the key channel of the distributional effects of monetary policy in the model. Figure 13 reports the estimated response of employment rates across the four income groups. As predicted by the model economy, households in the lower income quartile increase employment, while employment rates for richer households are not likely to respond to a monetary expansion.[52]

I also empirically document the asymmetric effects on earnings across the income distribution to monetary policy shocks. Figure 14 shows the estimated on-impact and three-year-average contribution rates of the employment and average earnings responses to the total earnings response across the income groups. Consistent with the model prediction found in Figure 5, the increased total labor income for the poor (first income quartile) is mainly due to a rise in employment, which contributes around 50 percent to the earnings response in that income group. In contrast, the earnings response for income-richest households (the fourth quartile) is mostly explained by changes in average earnings (earnings per employee).

5.2 Inequality and Monetary Effectiveness

In this subsection, I provide suggestive empirical evidence for the negative relation between long-run inequality and the monetary policy effectiveness by using state-level data in the U.S.

I use state-level datasets for inequality measures in the U.S. but consider national level shocks. By using state-level data with common shocks, I can address two potential problems in a country-level analysis: one is endogeneity problems due to considerable unobservable heterogeneity across countries, and the other is the normalization issue induced by different sizes of country-level monetary policy shocks. A state-level panel with national shocks in this study helps solve these two issues to some extent, since there might be relatively less heterogeneity across states within a country, and

[52] Note that since only annual data for employment rates across income quartiles are available in the CPS, the impulse responses in the VAR cannot be directly compared with those in the model, which is based on a quarterly frequency. In that sense, Figure 13 only shows suggestive empirical evidence for the model prediction: Figure 13 is *qualitatively* consistent with Figure 4, not *quantitatively*.

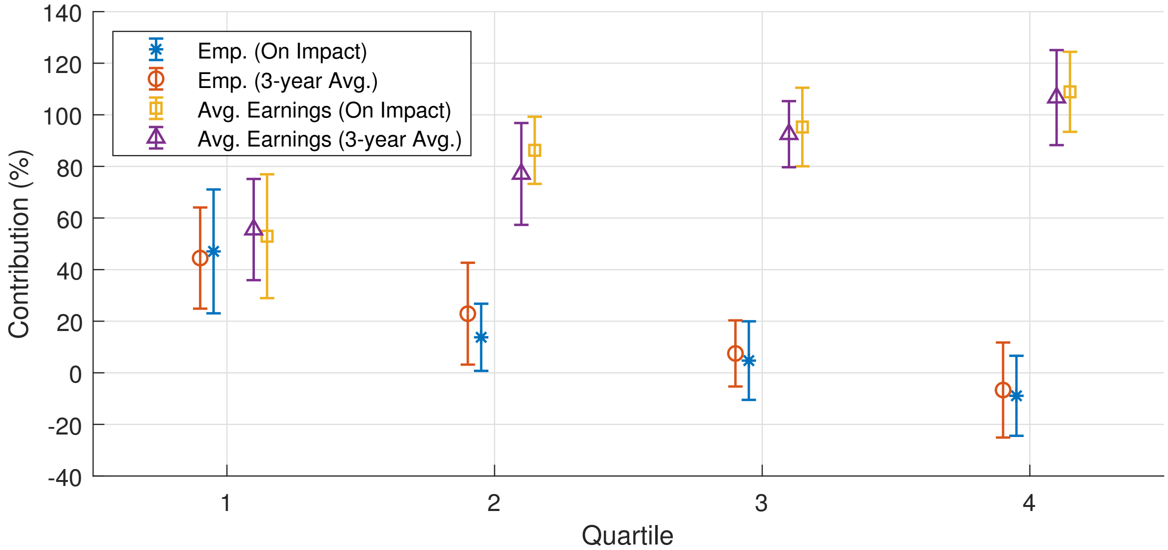

Figure 14: Decomposition of Earnings Responses: Data

Note: The figure shows on-impact and three-year-average contribution rates of the employment and average earnings responses across income groups to an expansionary monetary policy shock. Income is defined as the sum of labor, capital, and business income, while earnings are defined as the sum of labor income and business income. Bars represent the 68 percent confidence bands.

common policy shocks are automatically normalized across states, since each state faces the identical shocks.

For state-level real GDPs, I use annual data spanning from 1969 to 2006, from Nakamura and Steinsson (2014). Real GDPs are computed by using the national GDP deflator following Nakamura and Steinsson (2014). Data for state-level employment are from the Current Employment Statistics (CES) of the Bureau of Labor Statistics (BLS). Data on income inequality are from Frank (2014), who constructs the inequality measures by state using the pre-tax adjusted gross income published in the Internal Revenue Service (IRS). This is a broad measure of income, which includes wages and salaries, capital income such as dividends, interest, rents, and royalties, and entrepreneurial income including self-employment, small businesses, and partnerships. Regarding measures of income inequality, Gini coefficients of income are used for this empirical analysis. I use measures for monetary policy shocks developed by Romer and Romer (2004).

5.2.1 Evidence from Two-step Regression

In order to estimate the impact of the long-run level of inequality on the effectiveness of monetary policy, I employ a two-step approach. In the first step, I consider a three-variable VAR model including the monetary policy shock measure, federal fund rates, and GDP or employment for each state, and obtain the effect of monetary policy for state i, denoted by ζ_i. The second step is a cross-sectional estimation: I regress, ζ_i, on measures for inequality which are long-run averages across time for each state, i.

The left panel of Figure 15 shows the relation between the long-run level of inequality (defined as the average value of historical income Gini coefficients.) and the effectiveness of monetary policy

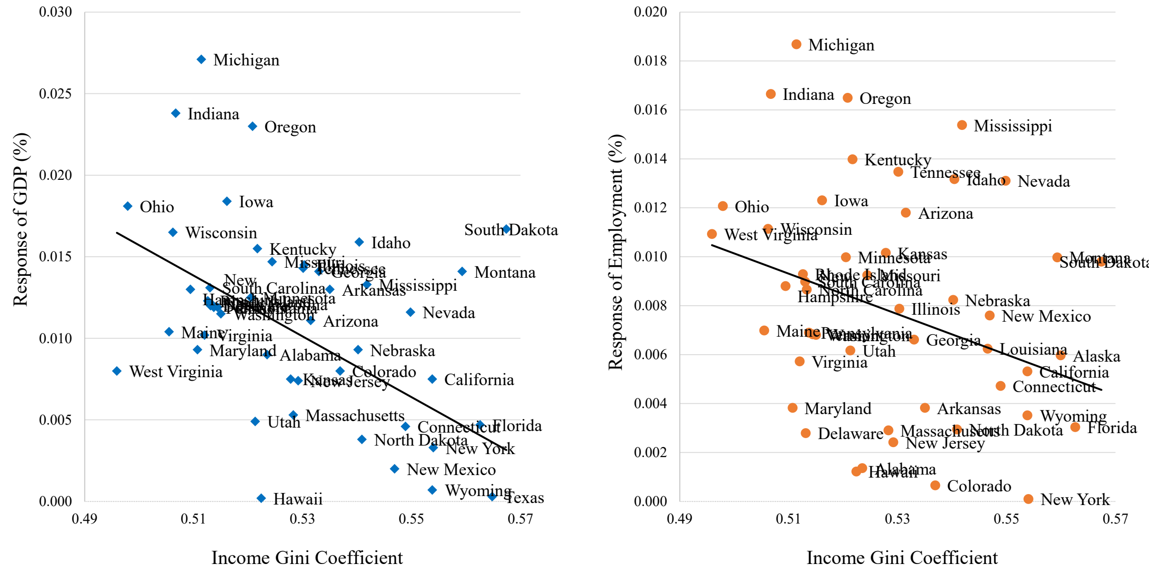

Figure 15: Inequality and Monetary Policy Effectiveness I

Note: The figure depicts the relation between the long-run level of inequality (defined as the average of historical income Gini coefficients) and the effectiveness of monetary policy across states, where the effectiveness is measured by the peak output (left panel) or employment (right panel) response to expansionary monetary policy shocks.

across states (measured by the peak output response to expansionary monetary policy shocks). As shown in the left panel of Figure 15, there is a negative relationship between inequality and the effectiveness of monetary policy.[53] The simple correlation between the two variables is -0.5. I regress the effectiveness of monetary policy on the long-run level of inequality. According to Table 4, the slope coefficient is negative and statistically significant: it is -0.18 and is significant at the 1 percent level.[54] It is also important to check whether the employment response is also negatively correlated with inequality, as this is the main mechanism of the model. As shown in the right panel of Figure 15, the long-run level of income inequality has a negative relation with the employment[55] response (the correlation coefficient is -0.34). The third and fourth columns in Table 4 report the cases where the effectiveness of monetary policy is measured by the peak response of employment. Notably, the coefficients for inequality are statistically negative, implying an inverse relationship between the employment response and a degree of income inequality. Therefore, as suggested by the model prediction, the long-run level of inequality may affect the magnitude of the employment response to a monetary shock, in turn affecting the size of the GDP response.

5.2.2 Evidence from Local Projection Method

As a robustness check, I also use local projection method proposed by Jorda (2005) to estimate impulse response functions (IRFs). The local projection method has been increasingly used in applied

[53] States that produce negative output responses are excluded in the figure since they are considered as outliers. Those states are Alaska, Oklahoma, and Louisiana.

[54] This result is still robust even when I include the long-run level of GDP per capita as a control variable (see Column (2)), and the estimation result is also robust when excluding the outliers.

[55] Employment is defined as the number of employees on nonfarm payrolls.

Table 4: Cross-sectional Estimation

Dependent Variable: Response of GDP or Employment	(1) GDP	(2) GDP	(3) Emp	(4) Emp
Constant	0.1067***	0.2221***	0.0760***	0.1231***
	(0.0325)	(0.0609)	(0.0173)	(0.0374)
Gini Coefficient	-0.1824***	-0.1658***	-0.0756**	-0.0648**
	(0.0619)	(0.0540)	(0.0327)	(0.0317)
GDP Per Capita		-0.0122**		-0.0079**
		(0.0053)		(0.0034)
Observation	50	50	50	50
R-squared	0.23	0.34	0.09	0.19

Note: The table shows the regression results for the relation between the long-run level of inequality and the effectiveness of monetary policy across states, measured by the peak output [columns (1) and (2)] or employment [columns (3) and (4)] response to expansionary monetary policy shocks. The long-run level of inequality is defined as the average of historical income Gini coefficients. Values in ( ) are White's robust standard errors. ** and *** indicate significance at the 5% and 1% levels, respectively. Per-capita GDPs are logged values.

work and can easily be extended to estimate state-dependent effectiveness of economic policies.[56] The local projection method for panel data simply estimates a series of regressions for each horizon j:

$$y_{i,t+j} = \alpha_{i,j} + \mathbb{I}^{H}_{i,t-1}[\beta_{H,j} Shock_t + \gamma_{H,j} x_{i,t}] + \mathbb{I}^{L}_{i,t-1}[\beta_{L,j} Shock_t + \gamma_{L,j} x_{i,t}] + \varepsilon_{i,t+j} \tag{14}$$

where $j = 0, 2, ..., J$; y is a variable of interest (logged GDP or logged employment); α is state-fixed effects which can control for unobserved cross-state heterogeneity; $Shock$ is monetary policy shocks; and x is a vector of control variables. x includes lagged policy shocks and lagged y. IRFs of y at time $t + j$ to the shock at time t can be obtained using the estimated coefficient $\beta_{H,j}$ and $\beta_{L,j}$. $\mathbb{I}^{H}_{i,t-1}(\mathbb{I}^{L}_{i,t-1})$ represents whether a state i is a high(low)-inequality state at time $t-1$. I use $\mathbb{I}^{H}_{i,t-1}$ in the regression rather than $\mathbb{I}^{H}_{i,t}$ since monetary policy at time t can affect inequality at time t. I set $\mathbb{I}^{H}_{i,t-1}(\mathbb{I}^{L}_{i,t-1}) = 1$ when a state i is one of the top (bottom) 10 states among 50 states in terms of the income Gini coefficient at time $t-1$ while $\mathbb{I}^{H}_{i,t-1}(\mathbb{I}^{L}_{i,t-1}) = 0$ otherwise.[57] Hence, $\beta_{H,j}$ is the coefficient associated with the high-inequality states for a horizon j, while $\beta_{L,j}$ captures the effects of the shock for low-inequality state for a horizon j.[58]

The estimated responses of GDP to expansionary monetary policy shocks in high- and low-

[56] Ramey and Zubairy (2018) use the local projection method to estimate impulse responses and government spending multipliers in the U.S., and Furceri et al. (2018) also study the effect of monetary policy shocks on income inequality using the local projection method with a panel of 32 countries.

[57] As a robustness check, I use various classifications (e.g., the top(bottom) 20 states or states whose inequality is larger(smaller) than the median), but the results are robust.

[58] Due to the small number of clusters, I do not use clustered robust standard errors, but the results with those errors are robust.

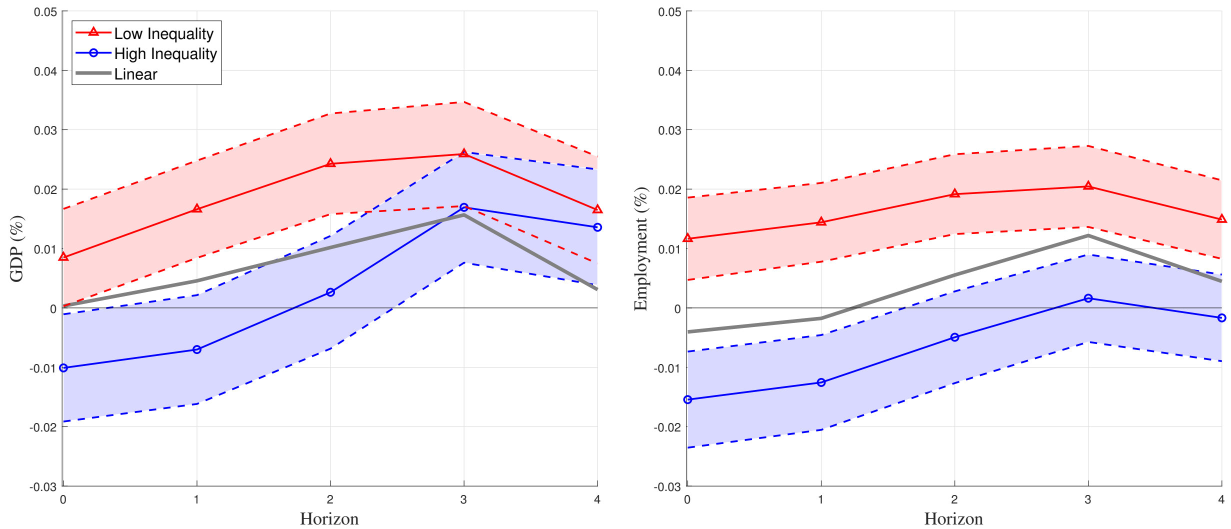

Figure 16: Inequality and Monetary Policy Effectiveness II

Note: The red lines with triangles show the output (left panel) and employment (right panel) responses to an expansionary monetary policy shock for the low inequality states while the blue lines with circles show those for the high inequality states. The gray thick solid line represents the unconditional output or employment response in the linear model. Newey-West standard errors are used, and 68% confidence intervals are shown with shaded area. The x-axis shows years after the shock.

inequality states are reported in the left panel of Figure 16.[59] The results of this exercise show that monetary policy shocks have much larger impacts on output in states of low inequality than high inequality. The effects of monetary policy shocks on impact are negative in states of high inequality, while the on-impact responses are positive when the economy features low inequality. There are statistically significant differences between the output responses for high- and low-inequality states for one and two years after the shocks. Importantly, as suggested by the model, the changes in GDP following a monetary shock may be driven by changes in the number of employees. The right panel of Figure 16 shows the estimated responses of the number of employees to expansionary monetary policy shocks for high- and low-inequality states. The employment response is large when the economy has low inequality, relative to that in high-inequality state. These empirical results support that a more equal society is associated with more effective monetary policy in terms of output and employment.

These findings are broadly consistent with those in the literature on the effectiveness of economic policy and inequality or indebtedness. Yang (2017) investigates the relationship between income inequality and the local government spending multipliers using rich historical state-level data on military procurement and inequality. He finds that the effects of government spending shocks on output are larger in low-inequality states than in high-inequality states. Alpanda and Zubairy (2017) also provide empirical evidence that the effects of monetary policy are less powerful during periods of high household debt. Similarly, Voinea et al. (2018) find that lower inequality is associated with stronger effectiveness and higher homogeneity of monetary policy transmission.

[59] To address the possible problem in the error terms induced by the successive leading of the dependent variable, I use the Newey-West correction, which is a standard correction method for the serial correlation problem in the literature, but the results with/without the Newey-West correction do not show any difference.

6 Conclusion

This study investigates the relationship between monetary policy and income inequality by asking how each affects the other: the effect of monetary policy on income inequality and the role of the long-run level of inequality in the effectiveness of monetary policy. To this end, I incorporate indivisible labor supply in a quantitative heterogeneous-agent New Keynesian economy in which both aggregate and disaggregate labor supply elasticities are endogenously generated. Two main findings emerge.

The first finding is that an unexpected monetary expansion decreases inequality. In this paper, I propose a new channel for the distributional effects of monetary policy: the heterogeneous labor supply elasticities across households. The indivisible labor supply assumption in the heterogeneous-agent model endogenously creates a substantial heterogeneity in labor supply elasticity across the income distribution (i.e., very high for the poor and almost zero for the rich). As a result, monetary expansion increases poor households' employment significantly, which causes income inequality to decrease.

I also find that a more equal economy tends to have more effective monetary policy. In this model, a degree of heterogeneity affects the size of aggregate labor supply elasticity. In the low-inequality economy, the elasticity of labor supply is larger, thereby flattening the NKPC. Thus, all else being equal, a more equal society has more effective monetary policy in terms of output.

Existing heterogeneous-agent New Keynesian models, including Kaplan et al. (2018) suggest that distributions of marginal propensity to consume (MPC) are crucial for accounting for the transmission mechanism for monetary policy. On the other hand, this study proposes a new perspective by suggesting that labor supply elasticity is important to explain both aggregate and disaggregate effects of monetary policy shocks.

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Appendix

A The Computational Algorithm

A.1 Steady-state (Stationary) Economy

The steps for the computational algorithm used for the steady-state economy are as follows.

Step 1. Have guesses for endogenous parameters.

Step 2. Construct grids for individual state variables, such as asset holdings, a, and logged individual labor productivity, $\hat{x} = \ln x$, where the number of grids for a and $\widehat{x}$ are denoted by N_a and N_x, respectively. I choose $N_a = 201$ and $N_x = 15$. The range of a is $[-1, 200]$. More asset grid points are assigned on the lower range using a convex function. $\widehat{x}$ is equally spaced in the range of $[-3\sigma_{\hat{x}}, 3\sigma_{\hat{x}}]$, where $\sigma_{\hat{x}} = \sigma_x/\sqrt{1-\rho_x^2}$.

Step 3. Approximate the transition probability matrices for individual labor productivity, $\mathbf{Q^x}$, using Tauchen (1986).

Step 4. Solve the individual value functions at each grid point. In this step, I obtain the optimal decision rules for saving $a'(\beta, a, x)$ and hours worked $h(\beta, a, x)$, the value functions $V^E(\beta, a, x)$, $V^N(\beta, a, x)$, and $V(\beta, a, x)$. The detailed steps are as follow:

(a) Compute the real wage rate in the steady state, $\overline{w}$, through the firm's first-order condition, where the steady-state capital return, $\overline{r}^k$, is chosen to be 0.01.

(b) Make an initial guess for the value function, $V_0(\beta, a, x)$ for all grid points.

(c) Solve the consumption-saving problem for each employment status to obtain $V_1^E(\beta, a, x)$ and $V_1^N(\beta, a, x)$.

(d) Compute $V_1(\beta, a, x)$ as $V_1(\beta, a, x) = \max\left\{V_1^E(\beta, a, x), V_1^N(\beta, a, x)\right\}$.

(e) If V_0 and V_1 are close enough for each grid point, go to the next step. Otherwise, update the value functions ($V_0 = V_1$), and go back to (c).

Step 5. Obtain the time-invariant measure, $\overline{\mu}$, with finer grid points for assets holding. $\overline{\mu}$ can be computed using the optimal decision rules and transition probabilities for β and x.

Step 6. Compute aggregate variables using $\overline{\mu}$. If targeted moments are sufficiently close to the assumed ones, then the steady-state equilibrium of the economy is found. Otherwise, reset the endogenous parameters, and go back to Step 2.

A.2 Economy with Aggregate Shocks

Below, I summarize the computational algorithm used for the dynamic model economy with monetary policy shocks. In order to solve the dynamic economy, I use the first moment of the distribution

Table A.1: ESTIMATES AND ACCURACY OF FORECASTING RULES

Dependent Variable	Coefficient Cons.	$\log K$	v	R^2	Den Haan (2010) Error Mean (%)	Max (%)
$\log K'$	0.1724	0.9252	-0.3866	0.9994	0.0838	0.3242
$\log Y$	-0.1533	0.0939	-1.2125	0.9693	0.0769	0.4637
$\log C$	-1.5697	0.5930	-0.7281	0.9974	0.0772	0.3669
$\log \Pi$	0.2664	-0.1157	0.8289	0.9999	0.0173	0.0681
$\log w$	-0.1494	0.3017	-2.8301	0.9988	0.0447	0.2904
$\log m$	0.2376	-0.1489	-3.3670	0.9999	0.0230	0.1138

(mean asset) and the forecasting function for it to solve a dynamic economy, following Krusell and Smith (1998).

Step 1. I construct grids for aggregate state variables, such as money supply shock and the aggregate capital, and individual state variables, such as the individual labor productivity and asset holdings. For the aggregate capital, K, and monetary policy shock, v, I construct five grid points for each of them. For the monetary policy shock, I construct five grid points in the range of $[-3\widetilde{\sigma}_v, 3\widetilde{\sigma}_v]$, where $\widetilde{\sigma}_v = \sigma_v/\sqrt{1-\rho_v^2}$. The grid points for K and v are equally spaced. The grids for individual state variables are the same as those in the steady-state (stationary) economy.

Step 3. I parameterize the forecasting functions for K', Y, C, Π, w, and m.

Step 4. Given the forecasting functions, I solve the optimization problems for the individual households.[60] I solve the optimization problems for individual households and obtain value functions, $V(\beta, a, x, K, v)$.

Step 5. I generate simulated data for 2,500 periods using the value functions for individuals obtained in Step 4.

Step 6. I obtain the new coefficients for the forecasting functions by the OLS estimation using the simulated time series.[61] If the new coefficients are sufficiently close to previous ones, the simulation is done. Otherwise, I update the coefficients and go to Step 4.

Table A.1 summarizes the estimated coefficients, the goodness of fit, and the accuracy of the forecasting rules. It is clear that R^2s for all forecasting functions are very large. I also check the accuracy of forecasting rules based on the statistics proposed by Den Haan (2010). I find that mean Den Haan (2010) errors are sufficiently small (not exceeding 0.1 percent), and maximum errors are also reasonably small (less than 0.5 percent) for all forecasting functions.

[60] Given the wage rate and the marginal cost, the real interest rate r^k can be computed from the firm's profit maximization.

[61] I drop the first 500 periods to eliminate the impact of the arbitrary choice of initial aggregate state variables.

B Data Sources

B.1 Aggregate Data

- Measures for Monetary Policy Shocks: Measures for monetary policy shocks are from Coibion et al. (2017). They update the measure of Romer and Romer (2004) up to the fourth quarter of 2008.

B.2 Micro-level Data

- Survey of Consumer Finance (SCF): Data for income, earnings, and wealth distributions are from Diaz-Gimenez et al. (1997), who summarize statistics regarding wealth, income, and earning inequalities using the 1992 SCF.

- Consumer Expenditure Surveys (CEX): Information for consumption distribution is from the 1992 Consumer Expenditure Surveys (CEX). The measure of non-durable consumption includes food and beverages, tobacco, apparel and services, personal care, gasoline, public transportation, household operation, medical care, entertainment, and reading material and education.

- Current Population Survey (CPS): Employment rates and transitory income shares across the income groups are from the Current Population Survey (CPS). In the CPS, employment statuses are determined based on whether the head of the household is employed, and transitory income is defined as labor income for salary workers and business income for self-employed workers.

B.3 State-level Data

- Income Inequality: Data on state-level income inequalities are taken from Frank (2014). Frank (2014) constructs the inequality measures by state using the pre-tax adjusted gross income published in the Internal Revenue Service (IRS).

- Real GDP: Data for state-level nominal GDPs are from Nakamura and Steinsson (2014). State-level real GDPs are computed by deflating them using the national GDP deflator.

- Employment: Employees on nonfarm payrolls. Data for state-level employment are from the Current Employment Statistics (CES) of the Bureau of Labor Statistics (BLS).

C Distribution of Countercyclical Profits

In model economies of monopolistic competition with nominal price rigidities only, markups are countercyclical, which implies negative profits in response to expansionary monetary policy shocks. Since the countercyclical markups or profits have counterfactual implications in the economy, how to distribute them matters for the monetary transmission mechanism. In this section, I compare

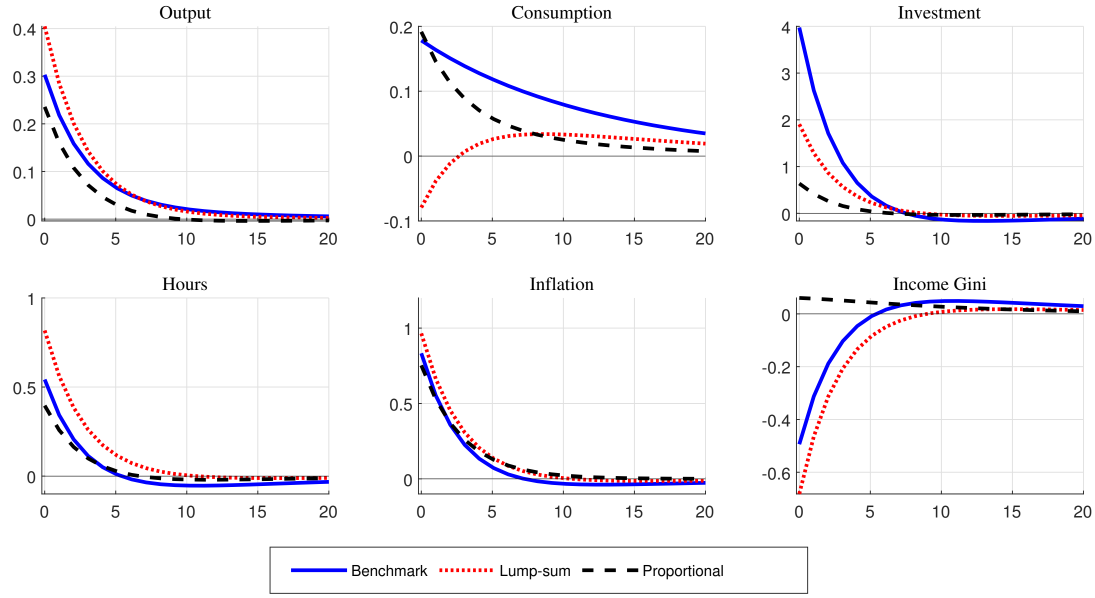

Figure A.1: Impulse responses of Key Aggregate Variables

Note: "Lump-sum" denotes the case where households earn lump-sum profit income from the monopolistic firms while "Proportional" denotes the case where profits are distributed depending on the level of wealth.

three model economies: i) the benchmark economy, where profit incomes are taxed at a rate of 100 percent and the government uses them for wasteful government consumption; ii) an economy where profits are equally distributed across households; and iii) an economy in which profits are distributed depending on the level of wealth.

Figure A.1 compares these three economies. In case that profits are equally distributed across households, the fall in profits associated with an expansionary monetary shock creates a negative wealth effect and decreases consumption, which is counterfactual. In the case that profits are distributed depending on the level of wealth, the countercyclical markups produce a downward pull on capital income, generating negative wealth effects for rich households. Hence, asset-rich households tend to work more, which causes a rise in income inequality. From this analysis, I argue that eliminating the countercyclical profits as in the benchmark economy is important for the transmission mechanism of monetary policy.