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

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Abstract

This study investigates the relation between monetary policy and income inequality by asking how one affects the other: the effect of monetary policy on income inequality and the impact of the long-run level of income inequality on the effectiveness of monetary policy. 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. I find that monetary policy shocks have distributional consequences due to a substantial heterogeneity in labor supply elasticity across households. I also show that a more equal economy is associated with more effective monetary policy in terms of output since it generates a larger aggregate elasticity of labor supply, thereby having a flatter New Keynesian Philips curve. Empirical evidence based on state-level panel data supports this model result.

JEL classification: E52, D31, D52, J21

Keywords: Monetary policy; Inequality; Labor supply elasticity; Indivisible labor

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1 Introduction

The unequal distributions of income and wealth have been a primary concern for economists and policy makers (Piketty, 2014; White House, 2017). In recent years, such inequality is particularly relevant for public debates on the disaggregate implications of economic policies since they might have disparate effects across different segments of the population. This study focuses on the relation between monetary policy and inequality. In principle, monetary policy and inequality can affect each other. On the one hand, unexpected monetary policy actions can have distributional effects on consumption, income, and wealth in the short run.[1] On the other hand, the level of inequality may affect the effectiveness of monetary policy in the long run.[2] Specifically, this paper studies both *the effects of monetary policy on income inequality* and *the role of the long-run level of income inequality in the effectiveness of monetary policy*, by answering the following questions:

1. How does unexpected monetary policy affect income inequality, and what is the key mechanism?
2. How does the long-run level of income inequality affect the effectiveness of monetary policy in terms of output, and what is the linkage?

In regards to the first question, an increasing concern about economic inequality has resulted in monetary policymakers discussing the potential distributional effects of monetary policy instruments (Mersch, 2014; Bullard, 2014; Bernanke, 2015). However, how monetary policy actions affect inequality is still ambiguous since there are a number of underlying channels as pointed out by Mersch (2014) and Bernanke (2015).[3] In this paper, I propose a new transmission mechanism of the distributional effects of monetary policy by developing a heterogeneous-agent New Keynesian model economy with indivisible labor.[4] In this model economy, a substantial heterogeneity in labor supply elasticity across households is important for explaining the disaggregate effects of monetary policy shocks.

As far as the second question is concerned, how the long-run level of economic inequality affects the effectiveness of monetary policy is also an important issue when considering different degrees of inequality across countries and increasing inequality over time. In spite of its importance, this topic is relatively unstudied in the literature, and existing papers (e.g., Kim (2017) and Cravino, Lan and Levchenko (2018))

[1] In this paper, I do not focus on the effect of systematic parts of monetary policy.

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

[3] Coibion et al. (2017) discuss the possible channels of the distributional effects of monetary policy: portfolio channel (households hold different financial assets), the savings redistribution channel (savers and borrowers are differentially affected by monetary policy), the financial segmentation channel (households have different access to financial markets and instruments). Auclert (2017) focuses on the three channels: an earnings heterogeneity channel from unequal income gains, the Fisher channel from unexpected inflation, and the interest rate exposure channel from real interest rate changes.

[4] Some recent studies in the literature provide channels of redistributive effects of monetary policy in the context of New Keynesian frameworks. For example, Kaplan, Moll and Violante (2018) focus on the role of the different marginal propensities to consume (MPC) across households by incorporating both liquid and illiquid assets, and Gornemann, Kuester and Nakajima (2016) build an incomplete asset market model where matching frictions create countercyclical labor-market risks.

do not have a general consensus.[5] Filling this gap is another primary goal of this study.

In order to study the relation between monetary policy and inequality, I develop a simple dynamic stochastic general equilibrium (DSGE) New Keynesian model which employs a continuum (measure one) of heterogeneous households, the central bank, the government, and firms. In the economy, asset markets are incomplete as in Huggett (1993) and Aiyagari (1994) in that households cannot fully insure against their idiosyncratic productivity shocks. This assumption, along with borrowing constraints, helps generate substantial heterogeneity across characteristics of individual households, including wealth, income, employment, and consumption. Following Hansen (1985), Rogerson (1988) and Chang and Kim (2007), it is assumed that a household indivisibly decides hours of work. The indivisible labor supply assumption in the incomplete market economy endogenously produces labor supply elasticity and its distribution across households, depending on how different individual reservation wages are compared to the market wage (Chang and Kim, 2006). The endogenous elasticity of labor supply is the key concept to answer for both aforementioned research questions. For the rest of the model, I follow standard New Keynesian models: monopolistically competitive firms facing nominal price stickiness set prices, and the economy is closed by monetary policy, which follows a standard Taylor rule.

One of the main findings is that expansionary monetary policy reduces income inequality. I propose a new channel for the effects of monetary policy on income inequality: heterogeneous labor supply elasticities across households. The discrete labor supply assumption endogenously creates decreasing 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. As a result, employment rises significantly from the bottom of the income distribution with expansionary monetary policy, which leads income inequality to decrease. I also provide supportive empirical evidence for the different responses of employment across income groups to monetary policy shocks using micro-level data. Monetary policy shocks also result in asymmetric effects on earnings, depending on relative responses of employment and average earnings: the poor benefit from an increase in employment whereas the rich benefit from a rise in average earnings in a relative sense.

A second important finding is that the long-run level of inequality matters for the effectiveness of monetary policy. 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, which allows us to uncover the aggregate 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 the 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 response of output to monetary policy shocks, implying that a low-inequality economy has a flatter New

[5] Kim (2017) finds that an economy when the poor consist of a larger share of the population has a smaller real effect of monetary policy shocks, but Cravino, Lan and Levchenko (2018) conclude that a change in the level of inequality does not significantly impact the responses of aggregate prices and output to monetary policy.

Keynesian Philips curve. Therefore, a more equal society is associated with more effective monetary policy in terms of output, *ceteris paribus*. I also provide empirical evidence for this model result using state-level panel data: the effects of monetary policy shocks on GDP are larger for low-inequality states.

This paper is organized as follows. Section 2 summarizes the related literature. Section 3 introduces a heterogeneous-agent New Keynesian model with indivisible labor. The distributional consequences of monetary policy are discussed in Section 4. Section 5 examines the role of the long-run level of inequality in the effectiveness of monetary policy. Section 6 concludes.

2 Related Literature

Some recent papers provide an insightful analysis of redistributive effects of monetary policy. Auclert (2017) finds that the effects of monetary policy on aggregate consumption tend to be amplified by redistribution channels. Kaplan, Moll and Violante (2018) introduce financial market incompleteness and two types of assets with different degrees of liquidity and different returns into a New Keynesian model. Their model successfully reproduces a wealth distribution, also across liquid and illiquid assets, and a distribution of the marginal propensities to consume (MPC). In this setting, Kaplan, Moll and Violante (2018) 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, which are mainly from intertemporal substitution effects. Gornemann, Kuester and Nakajima (2016) consider a model economy in which households differ in their employment status, earnings, and wealth in the context of New Keynesian frameworks. In their model, matching frictions create countercyclical labor-market risk, which is endogenous to monetary policy. Gornemann, Kuester and Nakajima (2016) find that contractionary monetary policy shocks increase inequality since the shock tends to prolong unemployment spells, as firms reduce labor demand. Another interesting result that they find is that a majority of households prefer substantial stabilization of unemployment even if this means deviations from price stability.[6] The current paper differs from the previous studies in the literature on the transmission mechanism of monetary policy in the presence of incomplete markets in that (i) this study focuses more on the distributional effects of discretionary changes in monetary policy actions;[7] (ii) the key monetary transmission mechanism for the distributional effects is generated by employment dynamics induced by different labor supply elasticities across households. Additionally, some empirical analyses study how the actions of the monetary authority affect inequality. The key contributions are Furceri, Loungani and Zdzienicka (2016) and Coibion et al. (2017). Their main finding is that a contractionary monetary policy shock increases inequality, which is consistent with the model result in this paper.

[6] Werning (2015) also studies some of the channels through which heterogeneity and incomplete markets imply a departure from the aggregate implications of the standard representative agent approach.

[7] The main focus of Gornemann, Kuester and Nakajima (2016) is on the heterogeneous welfare effects of *systematic* monetary policy while Kaplan, Moll and Violante (2018) decompose the transmission mechanism of monetary policy into direct and indirect general equilibrium effects on aggregate consumption.

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*. The other direction, *the effect of the long-run level of inequality on the effectiveness of monetary policy*, is relatively unstudied. A few studies on this issue exist. Using retail scanner and consumer panel data, Kim (2017) empirically documents that low-price brands change prices more frequently than high-price brands, and demand for low-price brands has a negative correlation with household income. Using a menu-cost model with vertically differentiated products and heterogeneous consumers, he concludes that the impact of monetary policy on real output decreases when there are more low-income consumers in the economy. Similarly, Cravino, Lan and Levchenko (2018) provide empirical evidence that the estimated impulse responses of high-income households' consumer price indices are lower than those of the middle-income households. Based on a quantitative New-Keynesian model with heterogeneous households where sectors are heterogeneous in their frequency of price changes, they conclude that a realistic change in inequality does not substantially affect the responses of aggregate prices and output to monetary policy. The current paper contributes to the literature by emphasizing the role of different aggregate labor supply elasticity depending on a degree of inequality in the causal relation between inequality and the effectiveness of monetary policy, while Kim (2017) and Cravino, Lan and Levchenko (2018) focus on the channels of different frequency of price changes and heterogeneous composition of consumption goods across households. The main result here is supported by empirical papers in the literature, such as Alpanda and Zubairy (2017) and Voinea, Lovin and Cojocaru (2018).[8] This paper is also related to the literature which discusses the relation between the long-run level of inequality and government spending multiplier (Brinca et al., 2016; Yang, 2017)[9] and studies which investigate an importance of micro-level heterogeneity in the propagation of aggregate shocks (e.g., Werning (2015) and Krueger, Mitman and Perri (2016)).[10]

3 Model Economy

To investigate the relation between monetary policy and inequality, I develop a quantitative heterogeneous-agent New Keynesian economy. There are four building blocks of the model economy: a continuum (measure one) of heterogeneous households, the monetary authority, the government, and firms. In the economy, households face idiosyncratic productivity shocks but cannot issue any assets contingent on their future idiosyncratic risks, which implies that asset markets are incomplete as in Huggett (1993) and Aiyagari (1994).

[8] Using Romanian data, Voinea, Lovin and Cojocaru (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.

[9] 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.

[10] 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, Mitman and Perri (2016) study the importance of household heterogeneity for aggregate consumption and output dynamics.

Since households face borrowing constraints and asset-market incompleteness, they will behave differently in response to monetary policy shocks, depending on individual state variables. Following Hansen (1985), Rogerson (1988) and 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 in which indivisible labor is introduced, both micro and macro labor supply elasticities are endogenously generated, depending on the shape of the reservation wage distribution (Chang and Kim, 2006)—how different individual reservation wages are compared to market wages. For the remaining blocks of the model economy, I employ standard assumptions in the New Keynesian literature: there are nominal price rigidities, monopolistically competitive producers set prices, and a central bank follows a conventional Taylor rule.

3.1 Households

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

$$\max \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\log c_t - \chi \frac{h_t^{1+1/\gamma}}{1+1/\gamma} \right) \right]$$

subject to

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

and

$$a_{t+1} \geq \underline{a},$$

where $0 < \beta < 1$ denotes the time discount factor, $\chi > 0$ is a parameter for disutility from working, and γ represents labor supply elasticity. Each household faces the budget constraints as in Equation 1. It is assumed that a household is endowed with one unit of physical time, which she allocates between hours worked and leisure. When a household works for h_t amount of hours, she earns $w_t x_t h_t$ as wage earnings, where w_t is the real wage rate for the efficiency unit of labor, and x_t denotes her labor productivity. A household can save or borrow by trading a claim for financial assets, a_t, which yields the real rate of return, r_t^k. The asset markets are incomplete following Huggett (1993) and Aiyagari (1994): households cannot issue any assets contingent on their future idiosyncratic risks x. A household faces a borrowing constraint that limits the fixed amount of debt: the assets holding, a_{t+1}, cannot go below $\underline{a}$ at any time. Labor productivity,

x, follows a stochastic process with transition probabilities $\mathit{\Gamma}_x(x'|x) = Pr(x_{t+1} = x'|x_t = x)$ and an AR(1) process in logs:

$$\ln x' = \rho_x \ln x + \varepsilon_x, \quad \varepsilon_x \sim N(0, {\sigma_x}^2).$$

Importantly, I assume that a labor supply decision made by a household is indivisible following Hansen (1985), Rogerson (1988) and Chang and Kim (2007): a household supplies a fixed amount 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 $\mathit{\Theta}$ as the vectors of individual and aggregate state variables, respectively: $\theta \equiv (a, x)$ and $\mathit{\Theta} \equiv (\mu, v)$, where $\mu(\theta)$ is the type distribution of households, and v is monetary policy shocks.[11] The value function for an employed household, denoted by $V^E(\theta, \mathit{\Theta})$, is defined as:

$$V^E(\theta, \mathit{\Theta}) = \max_{c,a'} \left\{ \ln c - \chi \frac{\overline{h}^{1+1/\gamma}}{1+1/\gamma} + \beta \mathbb{E}\left[V(\theta', \mathit{\Theta}')\right] \right\}$$

subject to

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

and

$$\mu' = \Psi(\mathit{\Theta}),$$

where Ψ denotes a forecasting function for μ. 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 $V^N(\theta, \mathit{\Theta})$, is defined as:

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

subject to

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

and

$$\mu' = \Psi(\mathit{\Theta}).$$

Then, the employment decision, $h(\theta, \mathit{\Theta})$, for a household is:

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

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

In the model economy with indivisible labor, a reservation wage rate (per effective labor) is an important concept for households to make their employment decisions. The reservation wage rate, denoted by $w^R(\theta, \Theta)$, is an individual subjective wage rate (per effective labor) which makes values when working and not working indifferent. Formally, under $w^R(\theta, \Theta)$, a value function for an employed household, $V^E(\theta, \Theta)$, and a value function for a non-employed household, $V^N(\theta, \Theta)$, are the same. A household is employed if the market wage rate, $w(\Theta)$, is equal to or larger than her reservation wage rate, $w^R(\theta, \Theta)$. That is,

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

Importantly, the reservation wage rate is different across households, depending on net wealth and productivity. Intuitively, $w^R(\theta, \Theta)$ is a decreasing function of labor productivity, x, and an increasing function of asset holdings, a.[12] When the market wage changes, the employment responses across households will be different. For example, a non-employed household having a reservation wage, which is close to the market wage, is more likely to be employed in response to an increase in the market wages. This implies that the model economy endogenously generates different labor supply elasticities across households.

3.2 Mutual Fund

In the model economy, there is no a portfolio choice by the individual households. Instead, a representative mutual fund exists which trades assets owned by all the households in the economy, and it invests all the assets on the firms. How to define a stochastic discount factor for the mutual fund matters since it is closely related to the monetary policy transmission mechanism in the economy. I assume that the mutual fund determines the price of claims based on the period-to-period valuation of a representative stock holder, who behaves according to the aggregate consumption dynamics. Hence, the implied stochastic discount factor between t and $t+1$, denoted by $Q_{t,t+1}$, is given by:

$$Q_{t,t+1} = \beta \tfrac{u_c(C_{t+1})}{u_c(C_t)},$$

where $u_c(\cdot)$ is the marginal utility of consumption, and C_t is aggregate consumption (i.e., $C_t = \int c_t(\theta_t, \Theta_t) d\mu_t$).[13] Abstracting public-sector debt or cash in the economy, I employ the cashless limit assumption widely used in the context of New Keynesian economies (Woodford, 1998; Gornemann, Kuester and Nakajima, 2016): the nominal interest on risk-free bonds, R_t, is controlled by the central bank. Accordingly, the optimal bond investment decision of the mutual fund implies a standard Euler equation:

[12] In the next section, I will discuss a graphical representation for the reservation wage schedules across individual types.

[13] Gornemann, Kuester and Nakajima (2016) assume that claims run by the mutual fund are priced based on the asset-weighted average of its shareholders' period-to-period valuation.

$$\mathbb{E}_t\left[Q_{t,t+1}\frac{R_t}{\Pi_{t+1}}\right]=1, \tag{4}$$

where Π_{t+1} is the gross rate of inflation between t and $t+1$. The Euler equation implies that others assets must be priced following the stochastic discount factor of the mutual fund. Thus, by changing the nominal risk-free rate under the sticky price, the central bank can affect the expected real rate of return, thereby affecting all other decisions in the economy.

3.3 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:

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

where z_t is aggregate productivity, $k_t(j)$ is capital used, $l_t(j)$ is effective labor, α is capital income share, and $f \geq 0$ is the fixed cost of production.[14] Aggregate productivity, z, follows a stochastic process with transition probabilities $\Gamma_z(z'|z)=Pr(z_{t+1}=z'|z_t=z)$ and an AR(1) process in logs:

$$\ln z'=\rho_z \ln z+\varepsilon_z, \quad \varepsilon_z \sim N(0,{\sigma_z}^2).$$

Since the firms face the same factor prices, the cost-minimization problem implies that they must all have the same capital-labor ratio and real marginal cost, ψ_t:

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

$$\psi_t=\Delta\frac{1}{z_t}r_t^k(j)^{\alpha}w_t(j)^{1-\alpha},$$

where $\Delta=(1-\alpha)^{\alpha-1}\alpha^{-\alpha}$. There is nominal price stickiness in the economy. Price adjustment is subject to a 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 $p_t(j)$:

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

subject to

$$y_t(j)=\left(\frac{p_t(j)}{P_t}\right)^{-\epsilon}Y_t, \tag{5}$$

[14]The fixed cost will be set to ensure that profits are zero in steady state, which rules out entry.

where the parameter, $\phi > 0$, is the extent of nominal rigidities, $\overline{\Pi}$ is the steady-state gross inflation, and $\epsilon > 1$ is the elasticity of substitution for intermediate goods. Equation 5 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:

$$1 + \tfrac{\phi}{\epsilon-1}\left(\Pi_t - \overline{\Pi}\right)\Pi_t - \tfrac{\epsilon}{\epsilon-1}\psi_t = \tfrac{\phi}{\epsilon-1}\mathbb{E}_t\left[Q_{t,t+k}\left\{\Pi_{t+1} - \overline{\Pi}\right\}\Pi_{t+1}\tfrac{Y_{t+1}}{Y_t}\right],$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$.

3.4 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:

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

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:

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

3.5 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 a conventional Taylor rule:

$$\ln R_t = \ln \overline{R} + \phi_\pi\left(\ln \Pi_t - \ln \overline{\Pi}\right) + \phi_y\left(\ln Y_t - \ln \overline{Y}\right) + v_t, \tag{6}$$

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. v_t is monetary policy shocks, which follow an AR(1) process with transition probabilities $\mathit{\Gamma}_v(v'|v) = Pr(v_{t+1} = v'|v_t = v)$:

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

In model economies of monopolistic competition with sticky prices only, markups are countercyclical, which implies negative profits in response to an expansionary monetary policy shock. However, there is abundant empirical evidence suggesting that countercyclical profits are counterfactual (e.g., Christiano, Eichenbaum and Evans (2005)). The countercyclical markups or profits have counterfactual implications in the economy. If profits are equally distributed across households, the fall in profits associated with an expansionary monetary shock creates a negative wealth effect, which may decrease consumption and shift the labor supply curve to the right. As discussed in Kaplan, Moll and Violante (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. In order to avoid theses counterfactual implications of nominal price rigidities, I assume that the government takes all the profits from intermediate-goods monopolistic firms and spends them as government consumption:

$$\xi_t = G_t,$$

where ξ_t is monopoly profits net of price adjustment costs, and G_t is government spending.[15] This assumption better explains the key mechanism of the model since it allows for abstracting the wealth effects associated with countercyclical profits on employment decisions of households, implying that (compensated) labor supply elasticities are the main driving forces of the labor supply choices in response to demand shocks.[16]

3.6 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:

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 $p_j(\Theta)$.

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 6).

6. Balanced budget of the government: $\xi(\Theta)=G(\Theta)$.[17]

[15] This means that households do not receive any profit income from intermediate-goods monopolistic firms as in Equation 1.

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

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

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 $Y(\Theta) = zK(\Theta)^{\alpha}L(\Theta)^{1-\alpha} - f$, $C(\Theta) = \int c(\theta, \Theta)d\mu$, $I(\Theta) = K'(\Theta) - (1-\delta)K(\Theta)$, and $\Xi(\Theta) = \frac{\phi}{2}(\Pi(\Theta) - \overline{\Pi})^2 Y(\Theta)$.

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

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

3.7 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 model economy.

The parameter, γ, which represents the micro elasticity of labor supply, is set to 0.4. This value is based on the findings that conventional micro estimates of the elasticity of labor supply are small $(0 - 0.5)$. It should be noted that since labor supply is assumed to be discrete, the value of γ does not affect the labor supply elasticity, and it is determined by the shape of the reservation-wage distribution. According to the Michigan Time-Use Survey, a typical household spends around one third of her discretionary time for working. Hence, fixed amount of hours worked, $\overline{h}$, is chosen to be 1/3. The time discount factor, β, and the disutility parameter of working, χ, are set so that quarterly return to capital is one percent (4 percent annualized), and the employment rate is 70 percent, respectively. For individual labor productivity shocks, previous studies in the literature, including Floden and Linde (2001), Chang and Kim (2006), and Chang, Kim and Schorfheide (2013), consistently report that the shocks are persistent, and the variance is also large. Following Chang, Kim and Schorfheide (2013), I set $\rho_x = 0.939$ and $\sigma_x = 0.287$, which are estimated with the AR(1) wage process from the Panel Study of Income Dynamics (PSID). The borrowing limit, $\underline{a}$, is -2.0, which is approximately double the quarterly average income in the model economy.[18]

Parameter values for production are quite standard. Aggregate productivity, z, is fixed at one. The capital income share, α, and the quarterly depreciation rate, δ, are calibrated to be 0.33 and 2.5 percent, respectively. The production fixed cost, f, is set for intermediate goods firm 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. The parameter for the Rotemberg price adjustment, ϕ, is set to 100, implying that firms, on average, update their price every 4 quarters given the choice of the elasticity of substitution.[19]

[18] This is consistent with the average unsecured credit-limit-to-income ratio of U.S. households (Chang, Kim and Schorfheide, 2013).

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

Table 1: Parameters of the Model Economy

Parameter	Value	Description	Source/Target Moments
		Households	
β	0.97927	Time discount factor	Real return to capital
$\overline{h}$	1/3	Extensive margin for hours worked	Standard
γ	0.4	Labor supply elasticity	Standard
ρ_x	0.939	Persistence of x shocks	Chang, Kim and Schorfheide (2013)
σ_x	0.287	Standard deviation of x shocks	Chang, Kim and Schorfheide (2013)
$\underline{a}$	-2.0	Borrowing limit	See text
		Firms	
α	0.33	Capital income share	Standard
δ	0.025	Capital depreciation rate	Standard
f	0.118	Production fixed cost	Zero profit
ϵ	10	Elasticity of substitution	11% markup
ϕ	100	Price adjustment cost	See text
		Monetary Authority	
ϕ_π	1.5	Weight on inflation	Standard
ϕ_y	0.25	Weight on output	Standard
$\overline{\Pi}$	1.005	Steady state gross inflation	Standard
$\overline{R}$	1.027	Steady state gross nom. interest	See text
ρ_v	0.7	Persistence of v shocks	Standard
$100 \times \sigma_v$	0.25	Standard deviation of v shocks	Standard

The Taylor rule coefficients of inflation and output, ϕ_π and ϕ_y, are chosen to be 1.5 and 0.25, respectively, which are conventional values in the New Keynesian literature. Regarding the monetary policy shocks, I choose $\rho_v = 0.7$ and $\sigma_v = 0.0025$. Given the value of standard deviation, σ_v, the annualized size of a typical monetary policy shock is 100 basis points. 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 4 in the steady state (i.e., $\overline{R} = \overline{\Pi}/\beta$).[20]

4 From Monetary Policy to Inequality

4.1 Aggregate Effects of Monetary Policy

In this section, I discuss the effects of an expansionary one-standard-deviation 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 20 quarters of horizon are shown in Figure 1.[21] The model economy inherits the typical feature in the context of standard New Keynesian models:

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

[21] See appendix for the impulse response to TFP shocks in the economy.

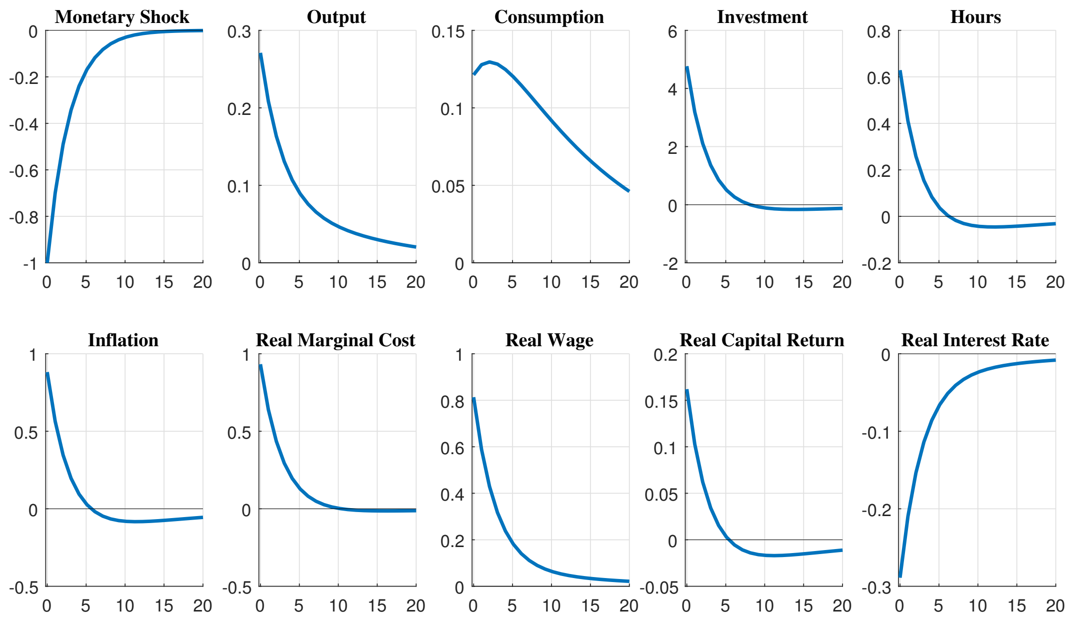

Figure 1: Impulse Responses of Aggregate Variables

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.

the key mechanism of an unexpected monetary easing on real economic activity in the model is through 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 0.27 percent and 4.8 percent, respectively. A fall in the long real rate of interest, combined with a rise in overall income, leads households to increase their consumption by 0.12 percent on impact. Finally, a 100-basis-point (annualized) monetary expending increases annualized inflation by 0.88 percent point. The dynamics of all the macro variables in the model economy is well-supported by the empirical literature (e.g., Christiano, Eichenbaum and Evans (2005)).

4.2 Distributional Effects of Monetary Policy

In this section, I investigate the effects of a monetary policy shock on inequality, focusing on the impact on income distribution. I first analyze whether the model economy produces reasonable heterogeneity across individual households and then investigate the transmission mechanism of the distributional effects of monetary policy. Finally, the role of the indivisible labor supply assumption in the distributional consequence of monetary policy will be discussed.

Table 2: Three Key Distributions

	Quintile					
	1st	2nd	3rd	4th	5th	Gini
U.S. Data						
Share of Income	2.18	6.63	11.80	19.47	59.91	0.57
Share of Wealth	-0.39	1.74	5.72	13.43	79.49	0.78
Share of Consumption	11.02	15.07	18.07	22.53	33.31	0.30
Model Economy						
Share of Income	1.34	5.74	12.64	23.59	56.68	0.55
Share of Wealth	-3.31	1.20	9.58	24.28	68.26	0.69
Share of Consumption	5.40	10.37	16.11	23.73	44.40	0.32

Note: Information for income and wealth in the data are from the Survey of Consumer Finances (SCF) 1992 in Diaz-Gimenez, Quadrini and Rios-Rull (1997), while statistics for consumption is the Consumer Expenditures Survey (CEX) average for the period 1968-2015.

4.2.1 Cross-sectional Distributions

As I investigate the distributional consequence of monetary policy shocks, I first analyze whether the model economy produces reasonable heterogeneity across individual households. Table 2 compares the detailed information on income, net asset holdings, and consumption in the model to the U.S data. The model economy reasonably replicates the income distribution of the U.S., making the income Gini index 0.57, which is comparable to the data (0.55). Consumption inequality is also well replicated by the model: the Gini index for consumption is 0.32 in the model, which is similar to what is observed in the U.S. data (0.30). The wealth distribution in the model economy is less concentrated compared to the U.S. data: the model economy makes the wealth Gini index about 0.69 while it is 0.78 in the U.S. data.[22]

It is also useful to discuss the reservation wage function generated by the model economy to have better understanding of the employment decisions for households, which is one of the key mechanisms for the distributional consequences of monetary policy shocks. Figure 2 displays the reservation wage (per effective labor) schedules, $w^R(a, x)$, over net wealth and productivity in the steady state. As briefly discussed earlier, the reservation wage is different 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 have two implications. 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 labor supply elasticities are also different across households, implying that there will be substantial heterogeneous employment responses to monetary policy shocks. For example, households, whose reservation wages were slightly larger than the market wage before the monetary policy shock hit, are likely to be newly-employed in response to an increase the market wage induced by an expansionary monetary policy shock. For example, since the reservation wage is a decreasing function of productivity,

[22] See Krusell and Smith (1998), Quadrini (2000), Castaneda, Diaz-Giminez and Rios-Rull (2003) and Cagetti and De Nardi (2006) for studies on replicating concentrated wealth distributions in the context of the heterogeneous-agent model frameworks.

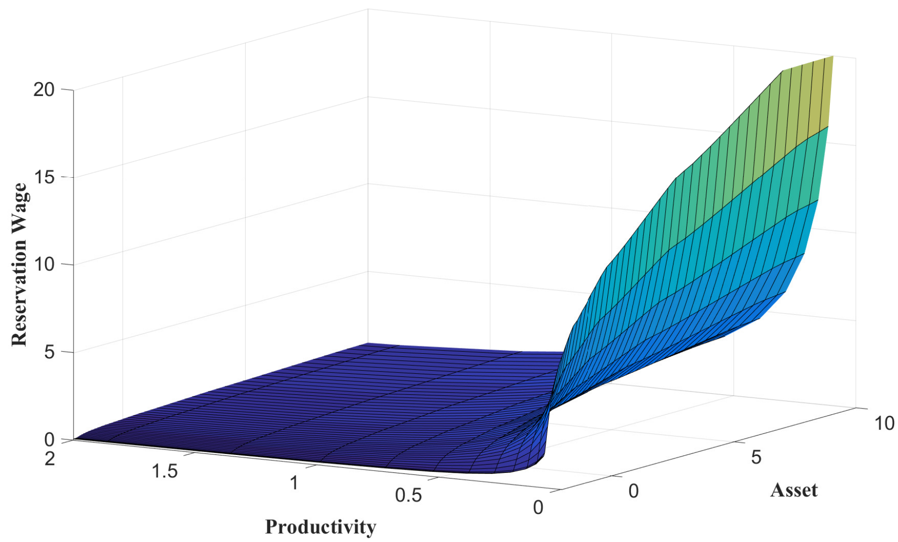

Figure 2: Reservation Wage Schedule over Productivity and Assets
Note: The figure shows the model-implied reservation wage (per effective) schedules over productivity and assets.

employment of households with relatively low productivity will be mostly affected by changes in monetary policy actions. This implies that monetary policy can have substantially different effects on households in the economy, depending on the size of individual elasticity of labor supply.

I next 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:

$$\log h_t = b_0 + b_1 \log w_t + b_2 \log c_t + \varepsilon_t. \tag{7}$$

The resulting parameter estimate b_1 is the labor supply elasticity. If a household with preferences as in the model makes divisible labor supply decisions, the first order condition of the household will imply that $b_1 = \gamma$. However, 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)). Moreover, in general, b_1 will be biased if shocks affect both aggregate labor demand and supply at the same time.[23] Since I shut down the wealth effects induced by the countercyclical profits,[24] the identification problem might be mitigated to some extent.

In Table 3, I report model-implied aggregate labor supply elasticity and the disaggregate labor supply

[23] Of course, b_1 can be also biased because the aggregation theorem does not hold in this economy due to asset market incompleteness (Chang and Kim, 2006).
[24] This implies that monetary policy shocks mainly shift the labor demand curve.

Table 3: Aggregate and Disaggregate Labor Supply Elasticities

	Income Quintile					
	1st	2nd	3rd	4th	5th	Aggregate
Benchmark	6.06	1.42	0.76	0.35	-0.02	0.94
Lump-sum Profit	11.56	1.43	0.55	0.23	-0.02	1.04
TFP Shock	5.42	1.23	0.76	0.56	-0.03	0.85

Note: All estimates are based on the OLS of Equation 3 using model-generated data (the quarterly time series of 2,000 periods). "Lump-sum Profit " denotes the case where households earn lump-sum profit income from the monopolistic firms while "TFP Shock" denotes the case where the model-generated data based on total factor productivity (TFP) shocks only are used for estimation.

elasticities across the income distribution.[25] As mentioned above, aggregate and disaggregate labor 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 0.94. This value is larger than the aggregate labor supply elasticity (0.70) 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 the correlation between changes in aggregate labor demand and supply.[26] An important finding in this section is that households have different labor supply elasticities across the income distribution. As is already conjectured 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.[27] The OLS estimate of the elasticity for the first income quintile is 6.06 while it is almost zero for the income-richest.[28] These results are robust to both cases i) where households earn lump-sum profit income from the monopolistic firms (in the second row of Table 3), and ii) where the model-generated data based on total factor productivity (TFP) shocks only are used for estimation (in the third row of Table 3). In the former case, an expansionary monetary policy shifts labor supply curve to the right since profits are countercyclical, which results in the over-estimated labor supply elasticity relative to the benchmark estimate. In the latter case, the estimate is smaller than that in the benchmark case since TFP shocks mainly affects the aggregate labor demand curve. The consistent results obtained from the two cases suggest that the identification problems discussed earlier may be systematic, and so the decreasing pattern of the elasticity across income quintiles is robust.

Considerable heterogeneity in labor supply elasticities across the income distribution implies that monetary policy can have substantially different effects on households' employment, thereby affecting individuals' consumption and saving decisions.

[25] R^2 for the regression based on the aggregate time series is 0.99, whereas R^2s of disaggreate data regressions vary from 0.11 to 0.98 due to the discrete choice of labor supply. The t-statistics are large, owing to a large sample size: all the estimates are individually statistically significant at the one percent level.

[26] 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.

[27] It should be noticed that transitions between income quintiles are allowed, so they may affect the estimates of b_1.

[28] The identification problems discussed earlier, along with transitions between quintiles, may yield the negative estimate of b_1 for the fifth quintile, but it is very close to zero.

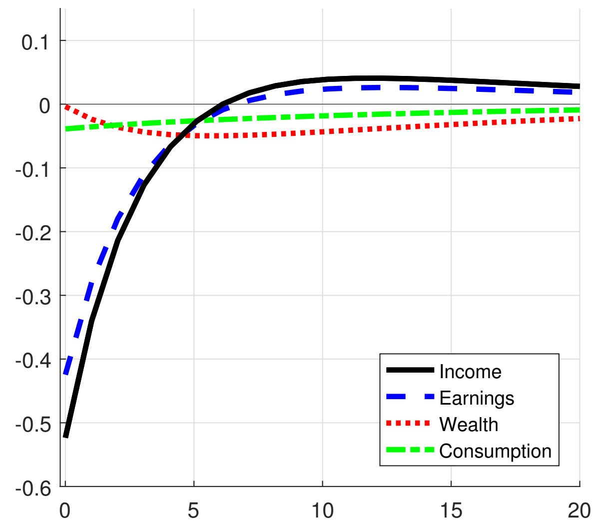

Figure 3: The Effects of Monetary Policy on Gini Coefficients

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.

4.2.2 Effect of Monetary Policy on Inequality

One of the main focuses of this study is on the distributional effects of monetary policy shocks. A rich heterogeneity across households including different labor supply elasticities suggests that monetary policy shocks could have sizable effects on inequality in the economy. Figure 3 depicts the effects of 100-basis-point (annualized) expansionary monetary policy shocks on Gini coefficients of income, earnings,[29] wealth, and consumption. A monetary expansion, indeed, decreases overall inequality in the economy, as is suggested by the empirical literature such as Furceri, Loungani and Zdzienicka (2016) and Coibion et al. (2017). A one-standard-deviation expansionary monetary policy shock reduces Gini coefficients of income, earnings, and consumption by 0.52, 0.43, and 0.04 percent, respectively. The response of consumption Gini 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 0.05 percent after 6 quarters of the shock.[30]

In this paper, I focus on the transmission channel through which an unanticipated monetary easing affects income inequality. Of course, there are many possible channels of the distributional effects of monetary policy. As discussed in Coibion et al. (2017), monetary policy can have an effect on inequality because i) households have different financial assets (portfolio channel), ii) savers and borrowers are differentially affected by monetary policy (the savings redistribution channel), and iii) households have different access to financial markets and instruments (the financial segmentation channel). Auclert (2017) also introduces three

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

[30] Regarding the wealth distribution, one may argue that an unexpected monetary policy would increase wealth inequality due to a rise in the capital return. However, if a huge increase in labor income of the new workers at the bottom of wealth distribution induces a large rise in their savings, then wealth inequality can decrease after the monetary easing. Both channels—a rise in capital income at the top vs. an increase in savings due to the employment effects at the bottom—coexist in this economy, but the latter effect is relatively large.

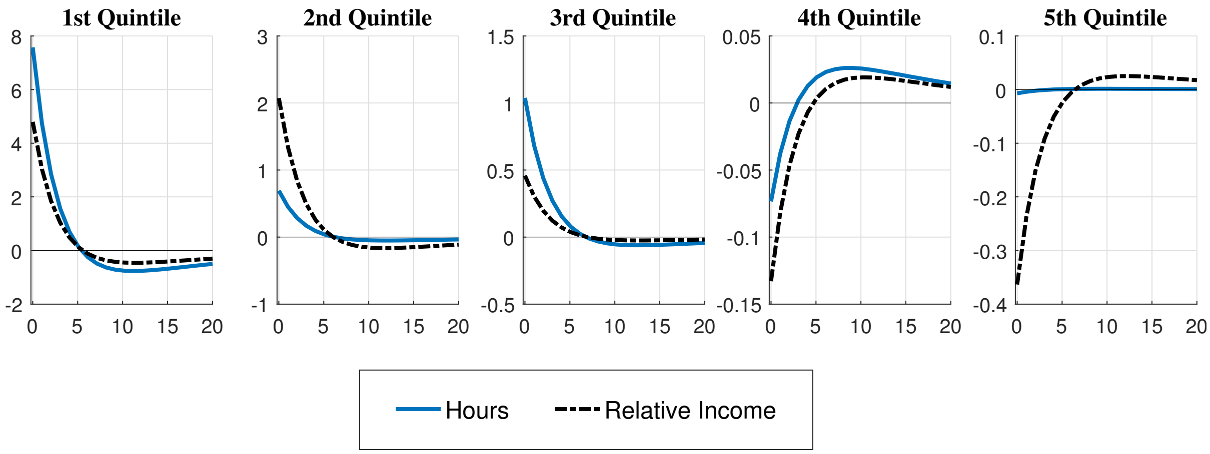

Figure 4: Responses of Relative Income and Hours
Note: The figure shows responses of relative income and hours across income distribution in the model. All the variables are logged, so the responses are percentage deviations from the steady state. The x-axis shows quarters after the shock.

important channels: an earnings heterogeneity channel from unequal income gains, the Fisher channel from unexpected inflation, and an interest rate exposure channel from real interest rate changes. In this paper, I propose a new channel for the effects of monetary policy on the income distribution: different labor supply elasticities across households.

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. As already noted, labor supply elasticity is larger for income-poor households relative to top income earners. Due to nominal rigidities, an expansionary monetary policy shock reduces the markups of intermediate goods firms, which leads intermediate goods firms 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 in response to an expansionary expansion, implying that newly-employed households tend to be less productive. Since labor income, which is associated with productivity, is the main source of total income, employment is likely to arise at the bottom of income distributions. One can interpret this result in the context 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.

To better understand why an unanticipated expansionary monetary policy reduces income inequality, it is instructive to inspect the responses of hours (or employment) and relative income to mean across the income distribution. Figure 4 compares the responses of hours and relative income across income quintiles in the model economy. As Figure 4 reveals, income-poor households tend to be newly-employed in response to an unexpected rise in money supply while employment falls for the rich households: hours worked in the

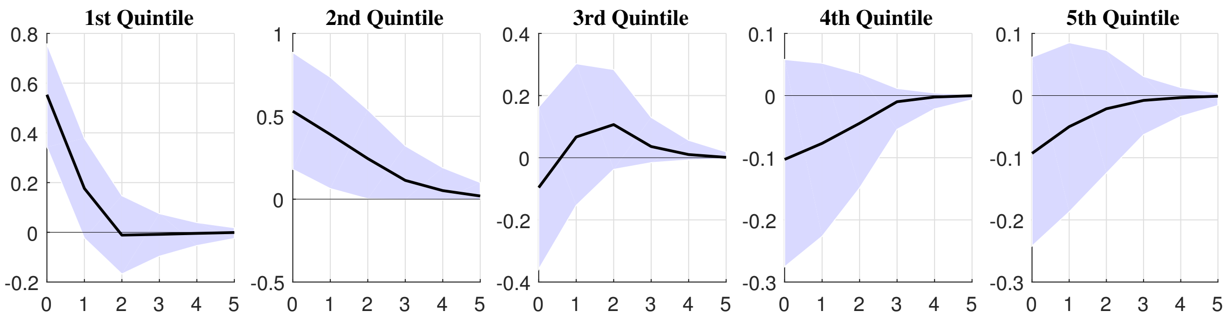

Figure 5: Response of Employment across Income Quintiles

Note: The figure presents the responses of employment across different income quintiles to an expansionary monetary policy shock. The y axis shows changes in percentage points, and the x-axis shows years after the shock.

first income quintile increase by 8 percent whereas households in the fourth and fifth income groups decrease employment by 0.07 percent and 0.007 percent, respectively.[31] The substantially-increased employment from the bottom of the income distribution leads to a fall in income inequality. The relative income for the poor increases while the rich lose their income in a relative sense, which makes the income Gini coefficient decrease on impact, as shown in Figure 3.

I next provide supportive 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. Toward this end, I use the Current Population Survey (CPS). Since information on income in the CPS is available in March of every year, I use annual data spanning 1969 to 2008. To estimate the effects of monetary policy shocks on employment by income, I employ a Vector Autoregressive (VAR), where measures for the monetary policy shocks[32] are ordered first,[33] and constant terms, quadratic trend terms, and a one-period lag are included. Figure 5 reports the estimated response of employment rates across five income groups. As predicted by the model economy, households in the lower income quintiles increase employment while employment rates for richer households do not change in response to a monetary expansion.

Another interesting implication of the distributional effects of monetary policy is from decomposition of changes in labor income (or 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 understand 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 6 separates the responses of the total earnings into employment and average earnings across the income quintiles in the model economy. As shown in Figure 6, the increased total labor income for the poor is mainly due to a huge rise in employment. For example, employment responses accounts

[31] Households in both fourth and fifth quintiles decrease their hours of work due to the wealth effects.

[32] Measures for monetary policy shocks are from Coibion et al. (2017). They update the measure of Romer and Romer (2004) until the fourth quarter of 2008.

[33] As discussed in Anderson, Inoue and Rossi (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 other variables respond to the shocks contemporaneously.

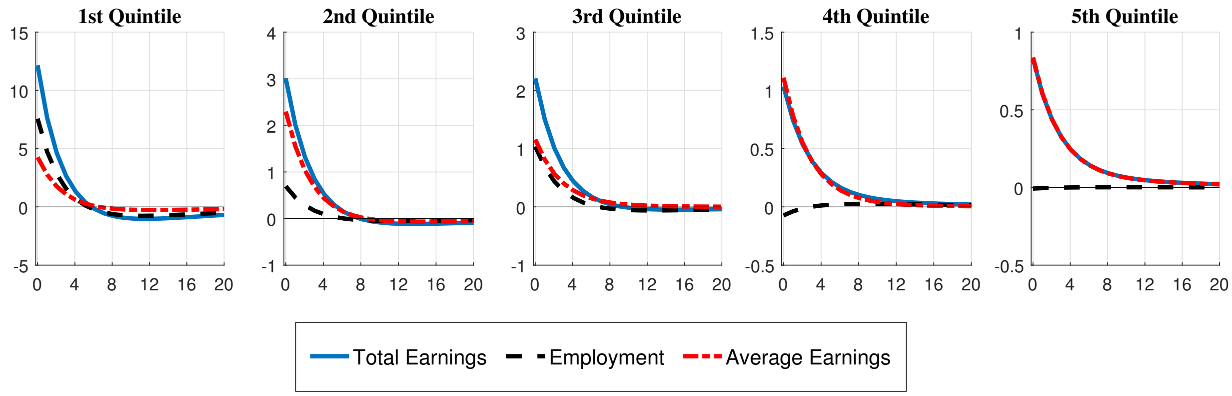

Figure 6: Decomposition of Earnings Responses
Note: The figure shows percentage changes in total labor income, employment, and average earnings to expansionary monetary policy shocks in the model economy. The x-axis shows quarters after the shock.

for more than 60 percent of an increase in earnings on impact for households in the first income quintile while the contribution rate of employment is almost zero percent for the fifth income group. Instead, the earnings responses for income-rich households are mostly explained by changes in average earnings rather than employment. Therefore, there are compositional effects of monetary policy on 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.

4.3 Role of Indivisible Labor

I next discuss the role of indivisible labor supply in the distributional consequence of monetary policy. As already noted, the discrete labor choice assumption allows for producing the heterogeneous elasticities of labor supply across income distribution: labor supply elasticity for income-poor households is very large while that of the top income earners is almost zero. To investigate the marginal contribution of the indivisible labor assumption, I consider a counterfactual economy with divisible labor. By construction, the elasticity is the same between the poor and the rich in the divisible labor economies. In short, the indivisible labor model produces heterogeneous elasticities across households whereas the model with a flexible hours decision generates homogeneous elasticity of labor supply across households.

Figure 7 compares the responses of key aggregate variables to a monetary policy expansion in the indivisible and divisible labor models. 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 divisible labor model economies, I consider two counterfactual economies with different parameters for labor supply elasticity. One case is $\gamma = 0.94$, which is the benchmark estimate of the elasticity based on aggregate data generated by the indivisible labor model (Table 3), the other case is $\gamma = 0.7$, which is the aggregate labor supply elasticity implied by the steady-state labor supply curve in the indivisible labor model. Since the elasticity of labor supply is homogeneous across productivity levels in the

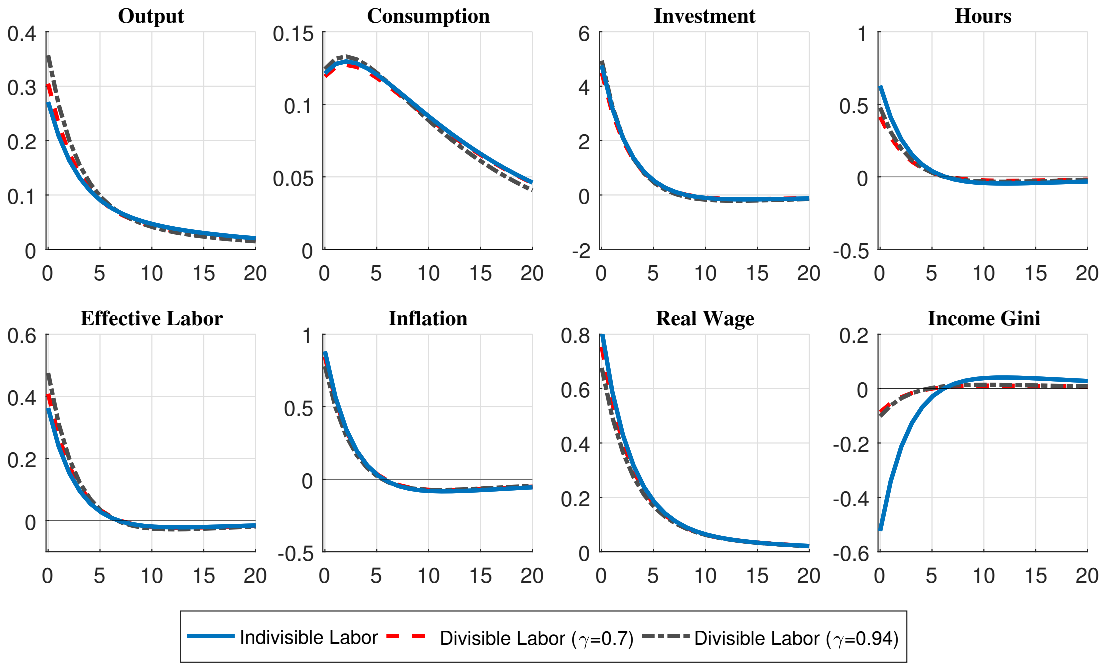

Figure 7: Indivisible vs. Divisible Labor Models

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 and dotted lines show counterfactual economies with divisible labor in which $\gamma = 0.7$ and $\gamma = 0.94$, respectively.

divisible labor models by construction, productive households in both divisible labor models (dented by the DL models) have relatively high elasticity of labor supply compared to those in the indivisible labor model (dented by the IL model).[34] For example, the model-implied labor supply elasticity for the fifth quintile in the DL model where $\gamma = 0.7$ ($\gamma = 0.94$) is around 0.73 (1.03) while it is nearly zero in the IL model. This implies that households with higher productivity also increase their hours of work in response to monetary policy expending in the DL models. Due to the increased hours from more productive households, the responses of aggregate effective labor is larger in the DL models than that in the IL model: the aggregate effective labor rises by 0.41 percent (0.48 percent) in the DL model in which $\gamma = 0.7$ ($\gamma = 0.94$), whereas it increases by 0.36 percent in the IL model. Finally, the DL models generate larger output responses given the similar (ideally, the same) aggregate labor supply elasticities to that in the IL model: output rises by 0.31 percent (0.36 percent) on impact in the DL model in which $\gamma = 0.7$ ($\gamma = 0.94$), while the output response is 0.27 percent in the IL model.

The central finding of this section is that income Gini in the DL model does not decrease by as much as in the IL counterpart in response to a monetary expansion. The sharply different labor supply elasticity distributions between the DL and IL models—the elasticity of labor supply is homogeneous across households in the DL models by construction, while the elasticities are different between the households in the IL model—lies at the heart of the response of income inequality. The two DL models produce very small

[34] In the the DL models, wages increase by less compared to those in the IL model because of the general equilibrium effects.

responses of the income Gini coefficient: the Gini index for income falls by around 0.1 percent in the DL models while it decreases by 0.52 percent in the IL model. This is because the homogeneous elasticity of labor supply in the DL models leads households to have the similar employment responses across income distributions, making the response of income Gini small.

The empirical literature shows that monetary policy shocks have a large effect on income inequality. Using 32 advanced economies and emerging market countries, Furceri, Loungani and Zdzienicka (2016) find that an unanticipated policy rate increase of 100 basis increases the income Gini index by about 1.25 percent in the very short term (one year after the shock) and by 2.25 percent in the medium term (5 years after the shock). Similarly, Coibion et al. (2017) report that income Gini inequality for the U.S. increases by approximately 2 percent (one percent point) in the medium term (5 years after the shock) given the cumulative size of the monetary policy tightening shock of one percent point. Therefore, the magnitude of the effect on income Gini in the IL model is in line with empirical magnitudes, but the DL models do not generate income Gini responses comparable to what we observe in the data.

5 From Inequality to Monetary Policy

I next turn to the other main contribution of this paper: the role of the long-run level of inequality in the effectiveness of monetary policy. What is the main linkage for the relation? 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. Next, 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 relation.

5.1 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, a size 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 larger 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 by decreasing standard deviation of the idiosyncratic shock process, where the income Gini index is around 10 percent less than that in the benchmark economy.[35] The reservation

[35] σ_x is set to 0.208 for the model economy with less heterogeneity. In the low-inequality economy, Gini indexes for income

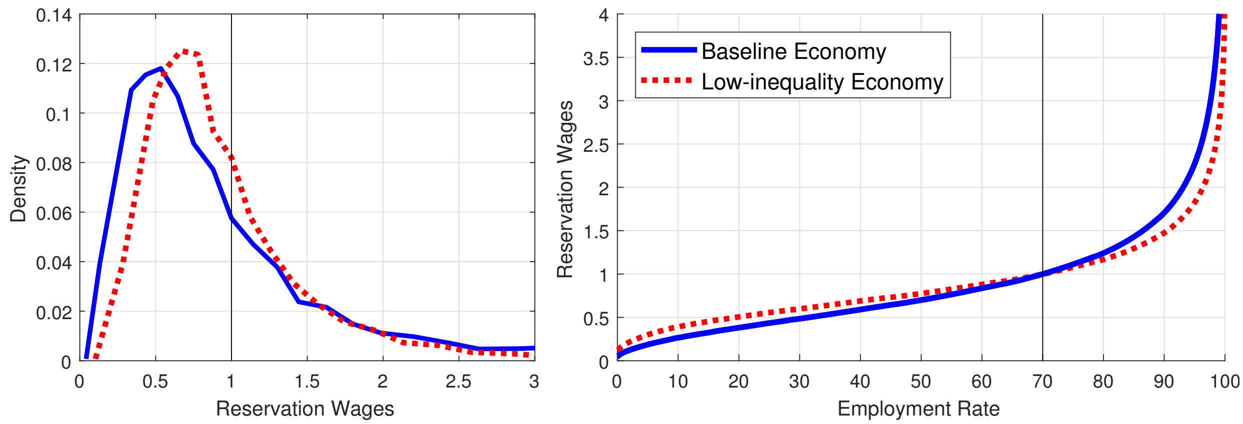

Figure 8: Labor Supply Curves with Different Heterogeneity

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 ($\sigma_x = 0.287$) while the dotted lines show a counterfactual economy with low inequality ($\sigma_x = 0.208$). The equilibrium wages in both economies are normalized at one.

wage schedule and invariant distribution across households uncover the aggregate labor supply curve of the economy. The left panel in Figure 8 plots distributions of reservation wages for the benchmark economy ($\sigma_x = 0.287$) and the counterfactual economy with low inequality ($\sigma_x = 0.208$).[36] As expected, the reservation wage distribution is more concentrated at the market wage in the low-inequality economy: the density at the market wage in the low-inequality economy is 0.82 while it is only 0.58 in the benchmark economy. In other words, there are more marginal workers around 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 8, 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 0.7 at the steady-state employment rate while the elasticity is 0.97 in the economy with a smaller degree of heterogeneity. As a result, a more equal economy has a larger size of labor supply elasticity, which will be the key linkage between the long-run level of inequality and the effectiveness of monetary policy.

and wealth reduce to 0.49 and 0.67, respectively.

[36] I normalize the equilibrium wages in both economies at one.

5.2 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 9 shows the responses of key aggregate variables of two model economies to monetary policy shocks: the economies where $\sigma_x = 0.287$ and $\sigma_x = 0.208$. As expected, the long-run level of inequality matters for the effectiveness of monetary policy. According to Figure 9, 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 that those in the benchmark case: GDP increases by around 0.42 percent in the economy with low-inequality while it rises by 0.27 percent in the benchmark counterpart. As already noted, the main mechanism of the larger effectiveness of comes from the labor supply elasticity, which represents the shape of reservation wage distribution. Since labor supply is much more elastic in the low-inequality economy, the response of hours is larger than that in the benchmark economy. Hours increase by 0.81 percent in the more equal economy whereas employment rises by 0.63 percent in the benchmark economy. Since marginal workers in the low-inequality economy are relatively homogeneous—the productivity difference between them is relatively small, the efficiency unit of labor per employment decreases by less in this economy (not shown in the figure). The interaction between the extensive margin (employment) and the intensive margin (effective labor per employment) leads both aggregate effective labor and output to increase by more in the economy with low inequality.

Another interpretation of this result comes from the slope of the New Keynesian Philips curve. In general, the linearized New Keynesian Philips curve is:

$$\pi_t = \frac{\epsilon - 1}{\phi}(\sigma + \eta)\widetilde{y_t} + \beta E_t \pi_{t+1} \tag{8}$$

where π_t is inflation, $\widetilde{y_t}$ is the output gap, σ is the inverse of the intertemporal elasticity of substitution, and η is the inverse of the labor supply elasticity. According to Equation 8, there is a negative relation between the slope of the New Keynesian Philips curve and the labor supply elasticity. Thus, higher labor supply elasticity in the low-inequality economy has a flatter New Keynesian Philips curve, thereby generating the larger real effects of monetary policy shocks. Interestingly, the flatter New Keynesian Philips curve in the low-inequality economy leads inflation to increase by less compared to that in the benchmark economy, but a difference in inflation responses in the two economies is very small relative to a gap between the output responses.

Another important finding in the section is that the long-run level of inequality matters for the distributional effect of monetary policy as well. As found in Figure 9, the response of income Gini is larger in the low-inequality economy than that in the benchmark counterpart: the income Gini index decreases by 0.85 percent in the more equal society while it falls by 0.52 percent in the benchmark model. Greater heterogeneity

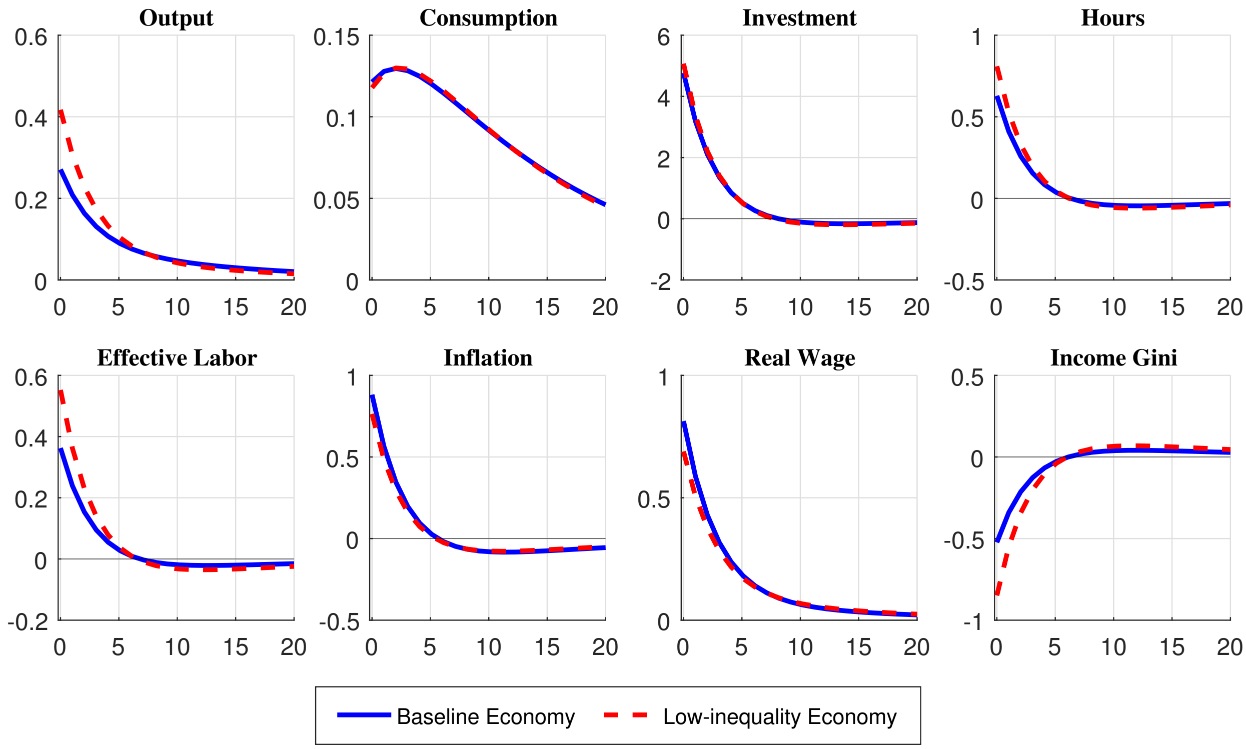

Figure 9: Responses of Key Variables with Different Heterogeneity

Note: The figure shows the responses of key aggregate variables to expansionary monetary policy shocks. The solid lines represent the benchmark economy ($\sigma_x = 0.287$) while the dotted lines show a counterfactual economy with low inequality ($\sigma_x = 0.208$).

in labor supply elasticity across households in the more equal economy decreases income inequality by more following a monetary expansion. More in 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 economy with low inequality, employment rises by more from the bottom of the income distribution, which leads income inequality to fall by more.

To sum up, different heterogeneity generates different macro labor supply elasticity, and it finally affects the effectiveness of monetary policy. All else being equal, a more equal economy has a larger effectiveness of monetary policy in terms of output responses.

5.3 Role of Discrete Labor Choice

The result above then raises a question: what is the role of the indivisible labor in the different responses of output 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. In divisible labor models, however, 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,

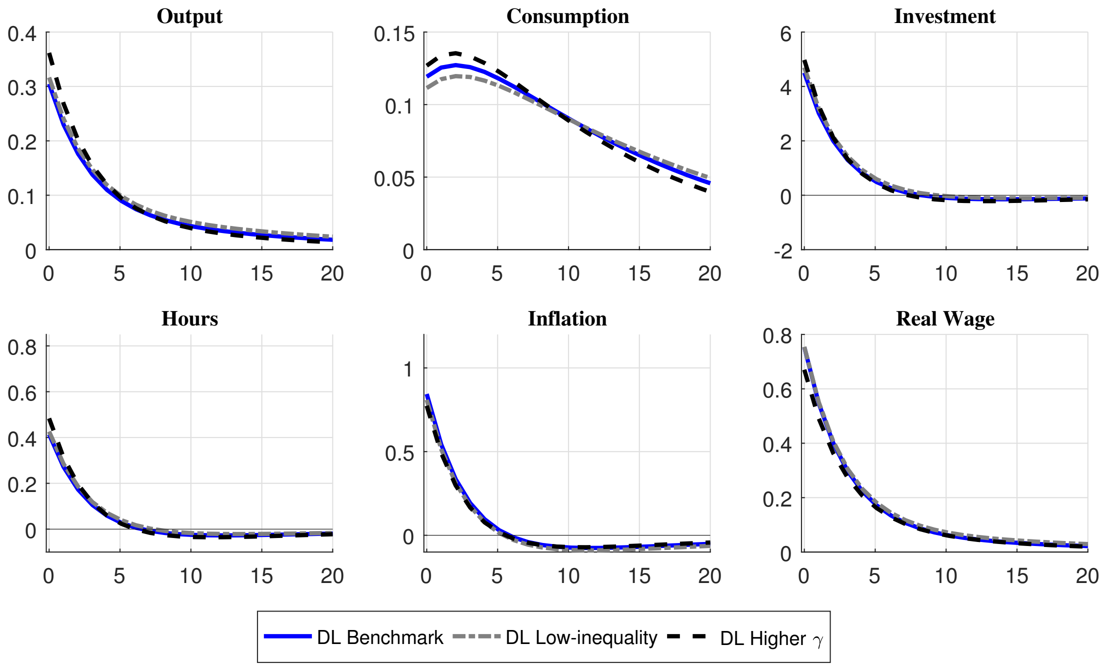

Figure 10: Responses of Key Variables with Different Heterogeneity

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 ($\sigma_x = 0.287$) and labor supply elasticity ($\gamma = 0.7$); "DL Low-inequality" refers to a divisible labor supply with smaller heterogeneity ($\sigma_x = 0.208$), keeping the labor supply elasticity the same; "DL Higher γ" refers to a divisible labor model with larger labor supply elasticity ($\gamma = 0.97$) with the benchmark heterogeneity.

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 ($\sigma_x = 0.287$) and labor supply elasticity ($\gamma = 0.7$); the second model economy that I consider allows for a divisible labor supply with a smaller heterogeneity ($\sigma_x = 0.208$), keeping the labor supply elasticity the same; the third model economy that I consider is a divisible labor model with a larger labor supply elasticity ($\gamma = 0.97$) with the benchmark heterogeneity. Accordingly, by comparing these three economies, I can analyze how important differences in a degree of heterogeneity and labor supply elasticities are for the responses of output in the model economies with flexible hours. Finally, one can find the role indivisible labor by comparing differences in output responses according to different heterogeneity in the indivisible labor models to those in the corresponding divisible labor models.

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 response of output. The model with a smaller heterogeneity does not generate a different output response from that in the model with benchmark heterogeneity since both economies have the same labor supply elasticity. This result suggests 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 only 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 responses of output in the divisible labor models. In the divisible labor model with a higher labor supply elasticity ($\gamma = 0.97$), output and hours increase by more: output and hours rise by 0.36 and 0.48 percent, respectively, when $\gamma = 0.97$ while the corresponding responses in the model with the benchmark elasticity ($\gamma = 0.7$) are 0.30 and 0.41 percent, respectively. An important finding is that a difference in output responses between the divisible labor models is relatively small compared to the output response gap between the corresponding indivisible labor models even if differences in aggregate labor supply elasticity are the same for the divisible and indivisible labor models. The initial response of output in the two divisible labor models differs by around 19 percent, but it differs more than 50 percent in the corresponding indivisible labor models. This result highlights an important implication of different underlying distribution of labor supply elasticity in the divisible and indivisible models—homogeneous vs. heterogeneous labor supply elasticities across households—for the effectiveness of monetary policy.

5.4 Empirical Evidence

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

5.4.1 Data

I use state-level data sets 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 that would occur 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 common policy shocks are automatically normalized across states since each state faces the identical shocks.

Data on income inequality are taken from Frank (2014), who constructs the inequality measures by state using the pre-tax adjusted gross income published in the Internal Revenue Service (IRS). Frank (2014) computes various measures of income inequality, including the relative mean deviation, Gini coefficient, Atkinson index, Theil's entropy index, as well as the top 1 percent and top 10 percent income shares. Among them, Gini coefficients are mainly used for this study. I use measures for monetary policy shocks developed by Romer and Romer (2004).[37]

[37] These measures are a combination of the use of Greenbook forecasts and narrative methods. Using narrative methods, Romer and Romer (2004) compute estimates of variations in intended federal funds rates during Federal Open Market Committee (FOMC) meetings. They then regress the intended federal funds rate on the output and inflation forecasts in the Greenbook at each FOMC meeting date and use the residuals as the monetary policy shocks. Based the method that Romer and Romer (2004) used, Coibion et al. (2017) extend the shock measures until 2008.

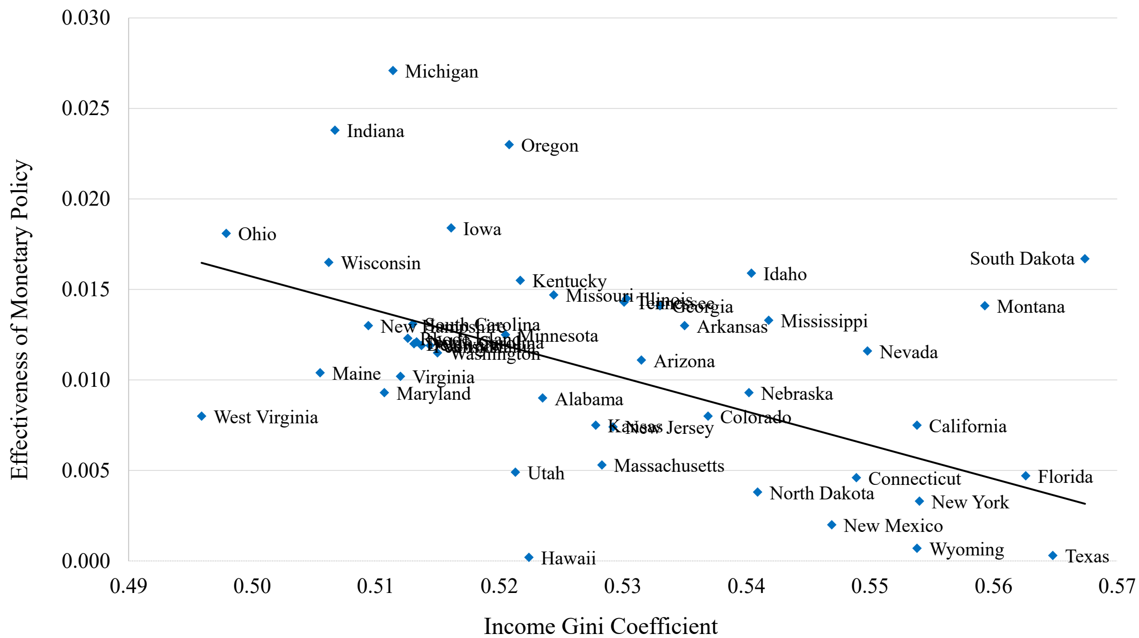

Figure 11: Inequality and Monetary Policy Effectiveness I

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

5.4.2 Estimation I: 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 Vector Autoregressive (VAR) model including the monetary policy shock measure, federal fund rates, and GDP for each state and to obtain the effect of monetary policy on output for state i, denoted by δ_i. The second step is a cross-sectional estimation: I regress δ_i on measures for inequality which are long-run averages across time for each state, i.

Figure 11 shows the relation between the long-run level of inequality and the effectiveness of monetary policy across states, where the effectiveness of monetary policy is measured by the peak output response to expansionary monetary policy shocks, and the long-run level of inequality is defined as the average value of historical income Gini coefficients. As shown in Figure 11, there is a negative relationship between inequality and the effectiveness of monetary policy.[38] 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 one percent level. This result is still robust even when I include the long-run level of GDP per capita as a control variable.[39]

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

[39]The estimation result is also robust when excluding the outliers.

Table 4: Cross-sectional Estimation

Dependent Variable: Effectiveness of Monetary Policy		
	(1)	(2)
Constant	0.1067***	0.2221***
	(0.0325)	(0.0609)
Gini Coefficient	-0.1824***	-0.1658***
	(0.0619)	(0.0540)
GDP Per Capita		-0.0122**
		(0.0053)
Observation	50	50
R-squared	0.23	0.34

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, where the effectiveness of monetary policy is measured by the peak output response to expansionary monetary policy shocks, and 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.

5.4.3 Estimation II: 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 work and can easily be extended to estimate state-dependent effectiveness of economic policies.[40] The local projection method for panel data simply estimates a series of regressions for each horizon j:

$$y_{i,t+j} = \alpha_{i,j} + \mathbb{I}^H_{i,t-1}[\beta_{H,j} Shock_t + \gamma_{H,j} x_{i,t}] + \mathbb{I}^L_{i,t-1}[\beta_{L,j} Shock_t + \gamma_{L,j} x_{i,t}] + \varepsilon_{i,t+j} \tag{9}$$

where $j = 0, 2, ..., J$, y is logged GDP, 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 a high(low)-inequality state for each state i 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.[41] 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.[42]

[40] Ramey and Zubairy (2018) use the local projection method to estimate impulse responses and government spending multipliers in the U.S., and Furceri, Loungani and Zdzienicka (2016) also study the effect of monetary policy shocks on income inequality using the local projection method with a panel of 32 countries.

[41] As robustness checks, 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.

[42] One complication associated with the local projection method in the panel study is covariance structures that vary by a

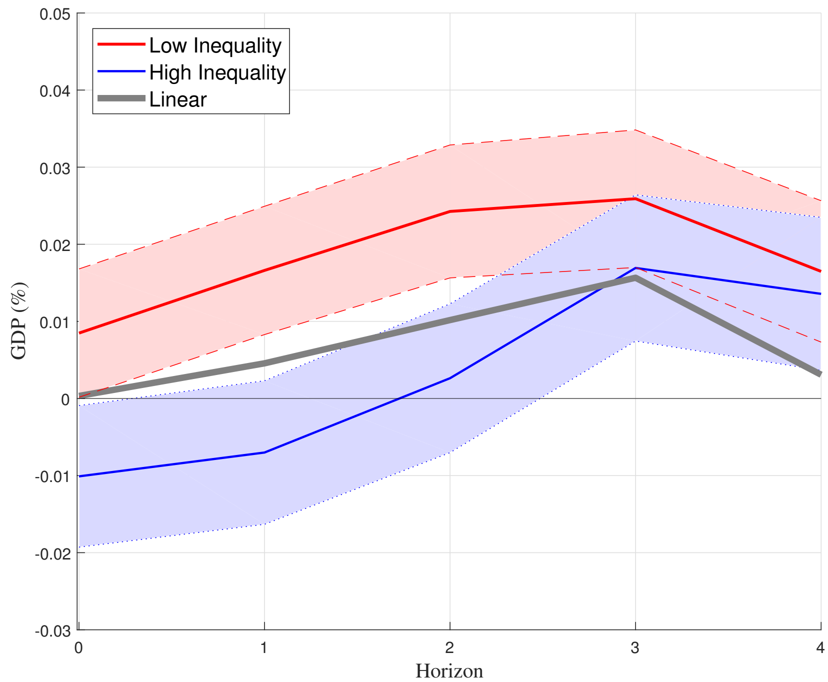

Figure 12: Inequality and Monetary Policy Effectiveness II
Note: The red lines (the blue lines) show the response of output to an expansionary monetary policy shock for the low (high) inequality states, and the gray thick solid line represents the unconditional response of output in the linear model. Newey-West standard errors are used, and 68% confidence intervals are shown with shaded area. The x-axis shows years after the shock.

The estimated responses of GDP to expansionary monetary policy shocks for states of high and low inequality are reported in Figure 12.[43] 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 are negative on impact in states of high inequality, while the on-impact responses are positive when the economy is experiencing low inequality. There are statistically significant differences between the responses of output for high- and low-inequality states for one and two years after the shocks. These empirical results provide supportive evidence that a more equal society is associated with more effective monetary policy in terms of output.

This empirical finding is 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,

certain characteristic. In order to address this issue, I have to use clustered robust standard errors, but the number of clusters is too small. Hence, I decide not to use clustered robust standard errors for the benchmark estimation, but the results with those error are still robust.

[43] 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.

Lovin and Cojocaru (2018) find that lower inequality is associated with stronger effectiveness and higher homogeneity of monetary policy transmission.

6 Conclusion

This study investigates the relation between monetary policy and income inequality by asking how one 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: the elasticity is very high for the poor while it is almost zero for the rich. As a result, monetary policy expending increases poor households' employment significantly, which leads 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 making the New Keynesian Philips curve flatter. Thus, all else being equal, a more equal society has a larger effectiveness of monetary policy in terms of output.

Existing heterogeneous-agent New Keynesian models including Kaplan, Moll and Violante (2018) suggest that distributions of marginal propensity to consume (MPC) are crucial to account 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

I summarize the computational algorithm used for the steady-state economy, which means that I find the stationary measure, $\overline{\mu}$. The steps are as follows.

Step 1. Have guesses for endogenous parameters such as β and χ.

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 $n_x = 17$. The range of a is $[-2, 200]$. 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, Γ_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 $a'(a,x)$ and hours worked $h(a,x)$, the value functions $V^E(a,x)$, $V^N(a,x)$, and $V(a,x)$. The detailed steps are as follows:

(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, $V_0(a,x)$ for all grid points.

(c) Solve the consumption-saving problem for each employment status:

$$V_1^E(a,x) = \max_{a' \geq \underline{a}} \left\{ \log\left(\overline{w}x\overline{h} + (1+\overline{r}^k)a - a'\right) \right.$$

$$\left. -\chi \frac{\overline{h}^{1+1/\gamma}}{1+1/\gamma} + \beta \sum_{x'=1}^{n_x} \Gamma_x(x'|x) V_0(a',x') \right\},$$

and

$$V_1^N(a,x) = \max_{a' \geq \underline{a}} \left\{ \log\left((1+\overline{r}^k)a - a'\right) + \beta \sum_{x'=1}^{n_x} \Gamma_x(x'|x) V_0(a',x') \right\}.$$

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

(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. Using cubic spline interpolation, compute the optimal decision rules for asset holdings with the new grid points. $\overline{\mu}$ can be computed using the new optimal decision rules and transition probabilities for x.

Step 6. Compute aggregate variables using $\overline{\mu}$. If the computed rental price for capital, the employment rate, and the price level become sufficiently close to the targeted ones, then the steady-state equilibrium of the economy is found. Otherwise, reset the endogenous parameters, and go back to Step 4.

A.2 Economy with Aggregate Shocks

I summarize the computational algorithm used for the dynamic model economy. In order to solve the dynamic economy, the distribution across households, μ, which affects prices, should be tracked. Instead, I use the first moment of the distribution 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 both 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, R, and ψ.

Step 4. Given the forecasting functions for K' and w, I solve the optimization problems for the individual households.[44] I solve the optimization problems for individual households and obtain the policy functions for asset holdings, $a'(a, x, K, v)$, and the employment decision rule, $h(a, x, K, v)$.[45]

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

(a) I set the initial conditions for K, v, and $\mu(a, x)$.

(b) Given the forecasting functions, I compute the gross nominal interest rate, R, the gross inflation Π, and marginal costs, ψ.

(c) Obtain the market-clearing wage, w. I choose $\hat{w}$ as a guess for w. Given the forecasting functions and the evaluated value function obtained in Step 4, I obtain the employment decision rule, $h(a, x)$. I check if the labor supply, $\int xh(a, x)$, is equal to labor demand. If not, reset $\hat{w}$.

[44] Given the wage rate and the marginal cost, the real interest rate r^k can be computed from the firm's profit maximization.
[45] As discussed earlier, the transition probabilities for x and v are approximated using Tauchen (1986).

(d) Given the forecasting functions, the evaluated value function obtained in Step 4, and obtained w and ψ, I solve the optimization problems for individual households to obtain the policy functions for asset holdings, $a'(a,x)$, and the employment decision rule, $h(a,x)$.

(e) I compute macro variables using μ: $C = \int c(a,x)d\mu$, $L = \int xh(a,x)d\mu$, $K' = \int a'(a,x)d\mu$, $H = \int h(a,x)d\mu$, $Y = K^{\alpha}L^{(1-\alpha)} - f$, and $I = K' - (1-\delta)K$.

(f) Obtain the next period measure $\mu'(a,x)$ using $a'(a,x)$ and transition probabilities for x.

Step 6. I obtain the new coefficients for the forecasting functions by the OLS estimation using the simulated time series.[46] If the new coefficients are close enough to the previous ones, the simulation is done. Otherwise, I update the coefficients, and go to Step 4.

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) until the fourth quarter of 2008.

B.2 Micro-level Data

- Income and Wealth Distributions: Data for income and wealth distributions are from Diaz-Gimenez, Quadrini and Rios-Rull (1997). Diaz-Gimenez, Quadrini and Rios-Rull (1997) summarize statistics regarding wealth, income and earning inequalities using the Survey of Consumer Finance (SCF) 1992.

- Consumption Distribution: Information for consumption distribution is from the 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, reading material and education.

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). Frank (2014) computes various measures of income inequality, including the relative mean deviation, Gini coefficient, Atkinson index, Theil's entropy index, as well as the top 1% and top 10% income shares.

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

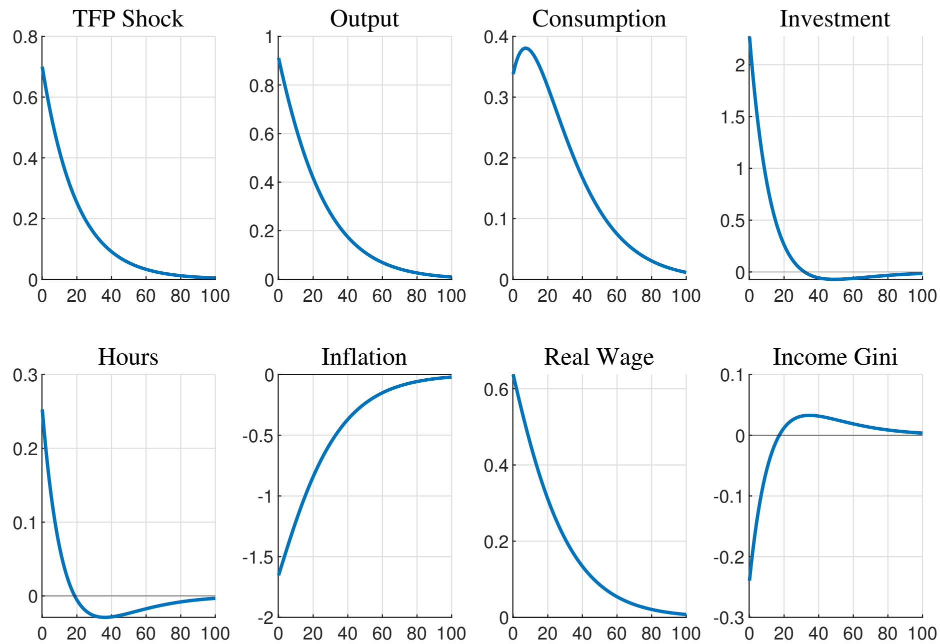

Figure A.1: Impulse responses to TFP Shock
Note: Impulse response to a one-standard-deviation TFP shock. For inflation the y axis shows changes in annualized percentage points, while for the remaining variables, the y axis shows percent changes. The x-axis shows quarters after the shock.

- 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.

C Additional Results

C.1 Transmission of Technology Shock

In this section, I discuss the effects of an expansionary one-standard-deviation TFP shock in the economy. Regarding the parameters for TFP shocks, I choose $\rho_z = 0.95$ and $\sigma_z = 0.007$. Figure A.1 reports the responses of key aggregate variables to expansionary TFP shocks for 100 quarters of horizon. The transmission mechanism of technology shocks on real economic activity in the model is through a rise in aggregate productivity. In response to an expansionary TFP shock, the overall productivity of intermediate goods firms increases, which shifts the aggregate supply curve to the right. The expending increases the demand for both labor and capital inputs and their prices, which leads households to work more and to increase consumption and saving at the same time. Therefore, output, consumption and investment rise by 0.91 percent, 0.34 percent, and 2.3 percent, respectively. A positive TPF shock decreases annualized inflation by around 1.7 percent point, which reflects an increase in aggregate supply in the economy. As expected, an expansionary technology shock also decreases income inequality, mainly due to a rise in employment from the bottom of the income distribution.

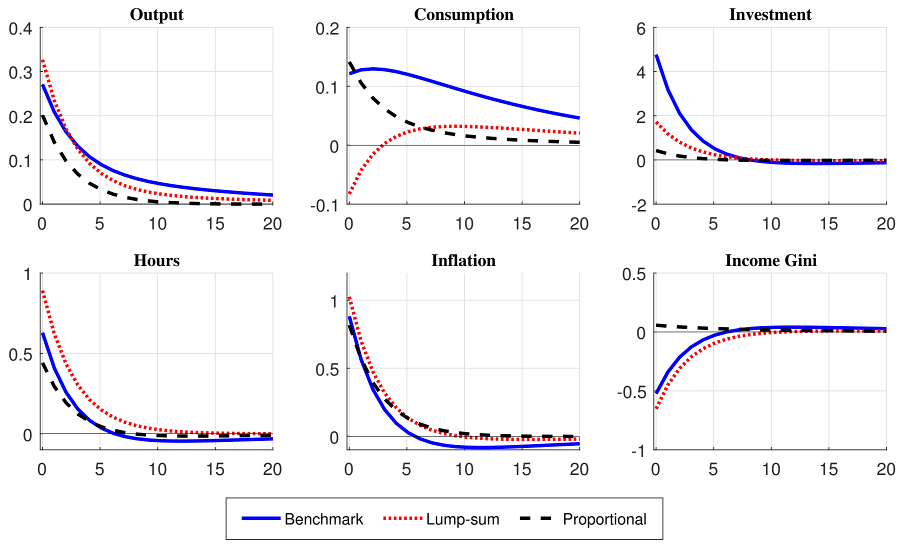

Figure A.2: Impulse responses of Key Aggregate Variables

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.

C.2 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 an expansionary monetary policy shock. 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 three model economies: i) the benchmark economy where the government takes all the profits from intermediate-goods monopolistic firms and spends them as government consumption; ii) an economy where profits are equally distributed across households; iii) an economy in which profits are distributed depending on the level of wealth.

Figure A.2 compares the three economies. If 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, which generates negative wealth effects for rich households. Hence, asset-rich households tend to work more, which leads income inequality to rise. From this analysis, I argue that excluding the countercyclical profits as in the benchmark economy is important for the transmission mechanism of monetary policy.