Intensive and Extensive Margins of Labor Supply in HANK: Aggaregate and Disaggregate Implications*

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September 5, 2022

Abstract

This paper studies how adjustment along intensive and extensive margins of labor supply affects aggregate and disaggregate effects of monetary policy. To this end, I develop a heterogeneous-agent New Keynesian (HANK) economy where a nonlinear mapping from hours worked into labor services generates operative adjustment along intensive and extensive margins of labor supply. I find that monetary policy has significantly different effects on earnings inequality, depending on the extent to which margin is dominant, even if it generates similar aggregate responses.

JEL classification: E52, D31, D52, J21
Keywords: Monetary policy; Intensive and extensive margins; Earnings inequality

*I would like to thank Sarah Zubairy, Greg Kaplan, Pedro Bento, Dennis Jansen, Yoon J. Jo, Joonseok Oh, Yuzhe Zhang, and seminar or conference participants at Texas A&M University, 90th Annual Meeting of the Southern Economic Association, and Bank of Korea for their valuable comments and suggestions. Part of this paper was being written while I was visiting the Bank of Korea. I am grateful for their hospitality during my stay at the Bank.

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1 Introduction

There have been recent advances in modeling aggregate labor supply that consider adjustment occurring along both intensive and extensive margins (Rogerson and Wallenius, 2009; Keane and Rogerson, 2012; Chang et al., 2019). Previous contributions to the business cycle literature have devoted a great deal of effort to having rich discussions about the relative importance of each margin (Heckman, 1984; Merkl and Wesselbaum, 2011; Ohanian and Raffo, 2012). For example, Chang et al. (2019) argue that the relative size of adjustment along intensive and extensive margins matters for the distribution of hours and aggregate fluctuations in a real business cycle (RBC) model. This paper extends this discussion to the New Keynesian literature. A natural question that has not been asked in the New Keynesian literature is how adjustment along intensive and extensive margins influences the monetary transmission mechanism. In particular, the impacts of monetary policy on inequality have received increasing attention from policymakers and economists (Gornemann, Kuester and Nakajima, 2016; Kaplan, Moll and Violante, 2018; Ma, 2019). In this regard, it is also crucial to see how the relative size of adjustment along intensive and extensive margins affects the distributional consequences of monetary policy. The main objective of this paper is to address these questions.

To give a concrete answer to the above questions, I follow Rogerson and Wallenius (2009) and embed a nonlinear mapping from time devoted to work to labor services in a New Keynesian economy with heterogeneous agents where operative intensive and extensive margins of labor supply are endogenously generated. The model economy features incomplete asset markets as in Huggett (1993) and Aiyagari (1994) and conventional assumptions in the New Keynesian literature, including sticky prices, monopolistic competition, and a standard Taylor rule. Hence, the model in this study is an extension of Chang et al. (2019) plus nominal price rigidity.

The model economy can successfully replicate the salient features of cross-sectional household heterogeneity found in the U.S. data. The model economy also produces empirically realistic responses of aggregate variables, including adjustment along both intensive and extensive margins, to a monetary policy shock.[1]

Having assessed the model's ability to account for distributions and aggregate responses in the data, I next examine how adjustment along both intensive and extensive margins influences aggregate and disaggregate impacts of monetary policy. The answer to this question depends on the extent to which margin is the dominant margin of adjustment. The relative size of adjustment along intensive and extensive margins is determined by the underlying primitives of the model economy. It is intuitive to think that the curvature parameter mainly determines intensive margin elasticity, while extensive margin elasticity is mostly determined by the degree of heterogeneity. Accordingly, in addition to an economy based on benchmark calibration, I consider two additional counterfactual economies with the different extent of heterogeneity and a different curvature parameter, respec-

[1] I find that the employment response is relatively important for accounting for the response of aggregate hours, but the response along the intensive margin plays a non-negligible role. I also provide empirical evidence for this model prediction.

tively, where both model economies are calibrated to match the same aggregate steady-state targets and generate the same response of total hours to a standardized monetary policy shock.[2]

The main important finding is that even if two economies generate similar aggregate behaviors in response to a monetary policy shock, the disaggregate effects can be significantly different, depending on the relative size of adjustment along the intensive and extensive margin. In response to an expansionary monetary shock, earnings inequality decreases substantially when the extensive margin is the dominant margin of adjustment, while it may increase in an economy with larger intensive margin adjustment. Hence, the extent to which margin of labor supply is dominant is important for accounting for the distributional effects of monetary policy.

Related Literature

Early studies featuring adjustment along both the intensive and extensive margins (e.g., Kydland and Prescott (1991) and Cho and Cooley (1994)) are based in the context of a representative household. Rogerson and Wallenius (2009) introduce a limited degree of heterogeneity into an economy with adjustment along both the intensive and extensive margins, but there is no aggregate uncertainty in their model. Chang and Kim (2006, 2007) study business cycles issues in the context of heterogeneous households but consider the extensive margin only. The work that is probably closest to this paper is Chang et al. (2019), who introduce intensive and extensive margins of labor supply in heterogeneous agent general equilibrium models to study business cycle fluctuations. Relative to Chang et al. (2019), this paper differs in that the main focus of this study is on accounting for the transmission mechanism of monetary policy rather than business cycles fluctuations.

This paper is related to several in the literature studying the transmission mechanism of monetary policy in the presence of incomplete markets. Auclert (2019) finds that the effects of monetary policy on aggregate consumption tend to be amplified by redistribution channels, such as earnings heterogeneity channels.[3] Kaplan, Moll and Violante (2018) consider two types of assets with different degrees of liquidity and returns in a New Keynesian model with incomplete financial markets and show that the indirect channels (general equilibrium effects such as an increase in labor demand) far outweigh the direct effects (intertemporal substitution channels). Werning (2015) also considers heterogeneity and incomplete markets to study the monetary transmission mechanism and finds that indirect effects offset direct channels in the presence of an incomplete market. Gornemann, Kuester and Nakajima (2016) develop a heterogeneous-agent model economy in the context of New Keynesian frameworks, where matching frictions create countercyclical labor-market risk. They find that a majority of households prefer substantial stabilization of unemployment, even if this means deviations from price stability. Ma (2019) considers extensive margins of labor supply in a heterogeneous-agent New Keynesian model where both macro and micro labor supply elasticities are endogenously generated and finds that a substantial heterogeneity in labor supply elasticity across

[2] Chang et al. (2019) also consider various specifications that feature different degrees of heterogeneity and a set of values for the curvature parameter.

[3] Coibion et al. (2017) empirically documents an earnings heterogeneity channel for the distributional effects of monetary policy.

households plays a crucial role in explaining both aggregate and disaggregate effects of monetary policy shocks. The current paper contributes to this literature by incorporating adjustment along both the intensive and extensive margins and emphasizing the role of each margin for the monetary transmission mechanism. To the best of my knowledge, this study is the first to embed adjustment along the intensive and extensive margins in the context of a heterogeneous-agent New Keynesian economy.

The study is organized as follows. Section 2 specifies the benchmark model economy with operative intensive and extensive margins. Section 3 assesses the extent to which the benchmark model captures the salient features of the empirical cross-sectional distributions and produces empirically realistic aggregate and disaggregate responses to monetary policy shocks. The extent to which adjustment along the intensive and extensive margin affects aggregate and disaggregate effects of monetary policy is examined in Section 4. Section 5 concludes.

2 Model Economy

2.1 Households

There is a unit measure of ex-ante identical infinitely lived households whose mass is normalized to one. Each household has preference over streams of consumption, c_t, and hours of work, h_t :

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

where $0<\beta<1$ denotes the discount factor; $\lambda>0$ denotes disutility from working; and $\gamma>0$ is a parameter for a curvature in preferences over hours of work. It is assumed that a household is endowed with a unit of time in each period.

Households are subject to idiosyncratic labor productivity shocks, denoted by e_t, which follow a stochastic process, where the realizations are independently and identically distributed across households. It is assumed that e_t follows an AR(1) process in logs:

$$\ln e_{t+1}=\rho_e\ln e_t+\varepsilon_{t+1}^e,\quad \varepsilon_{t+1}^e\sim N(0,{\sigma_e}^2).$$

In order to operate adjustment along both intensive and extensive margins of labor supply, I assume a nonconvexity in the mapping from time devoted to work into units of labor services. The mapping from hours of work into the resulting labor services is assumed such that, if a household with labor productivity of e provides h units of time to firms, it will generate $g(h)e$ efficiency units of labor. Thus, the function, $g(h)$, plays a critical role in the analysis. Following Rogerson and Wallenius (2009) and Chang et al. (2019), I assume that $g(\cdot)$ takes the simple form:

$$g(h)=\max\left\{h-\underline{h},0\right\},h\in[0,1], \tag{1}$$

where $0 < \underline{h} < 1$. The above functional form implies that hours devoted to market work have a convex relation with the resulting labor services or labor earnings. One justification for the nonconvexity is factors such as set-up costs, costs associated with being supervised, and costs associated with the need to coordinate with other workers (Rogerson and Wallenius, 2009; Chang et al., 2019).

Each household faces the budget constraints:

$$c_t + a_{t+1} = w_t g(h_t) e_t + (1 + r_t^a) a_t - T_t + \varphi_t, \tag{2}$$

and

$$a_{t+1} \geq \underline{b}. \tag{3}$$

When a household devotes h_t units of hours to market work, the resulting wage earnings are $w_t g(h_t) e_t$, where w_t is the real wage rate for the efficiency unit of labor. A household should pay a lump-sum tax, T_t and earns profit income, φ_t. Following Huggett (1993) and Aiyagari (1994), I assume that asset markets are incomplete in the sense that individual households cannot issue any assets contingent on their future idiosyncratic risks. A household trades claims to financial assets, a_t, which yields the real rate of return, r_t^a, but trade in these claims is subject to an exogenous borrowing constraint as in Equation 3: the assets holding, a_{t+1}, cannot go below $\underline{b}$ at any time. Credit constraints along incomplete asset markets allow monetary policy shocks to affect households differently depending on the level of individual productivity and asset holdings.

Household's problem It is useful to consider a recursive form for a household's problem. Define x and X as the vectors of individual and aggregate state variables, respectively: $x \equiv (a, e)$ and $X \equiv (\mu, \varsigma)$, where $\mu(x)$ is the type distribution of households, and ς is an aggregate shock of interest such as monetary policy shocks.[4] To simplify notation, I suppress time subindices, and variables with primes denote variables in the next period. The value function for a household, denoted by $V(x, X)$, is defined as:

$$V(x, X) = \max_{c,a',h} \left\{ \ln c - \lambda \frac{h^{1+1/\gamma}}{1+1/\gamma} + \beta \mathbb{E}\left[V(x', X')\right] \right\}$$

subject to

$$c + a' = wg(h)e + (1 + r^a)a - T + \varphi,$$

$$a' \geq \underline{b},$$

[4] The measure $\mu(a, e)$ is defined over a σ-algebra of $\mathcal{A} \times \mathcal{E}$, where $\mathcal{A}$ and $\mathcal{E}$ denote sets of all possible realizations of a and e, respectively.

and

$$\mu' = \Gamma(X),$$

where Γ denotes a transition operator for μ.

2.2 Final Goods Firm

There is a continuum of perfectly competitive final goods firms, which are uniformly distributed on the interval $[0, 1]$. The representative final good firm produces a homogeneous output, Y_t, by combining intermediate goods, according to the constant elasticity of substitution technology:

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

where $y_t(j)$ is the intermediate good variety j, and $\epsilon > 1$ is the elasticity of substitution for intermediate goods. Since final goods firms are perfectly competitive, they take the final good price, P_t, as given. Cost minimization problem for the final good firm, along with the zero-profit condition, implies that the demand for intermediate good j is given by:

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

where $p_t(j)$ is the price of the jth intermediate input.

2.3 Intermediate Goods Firms

There exists a continuum of intermediate goods producers in a monopolistically competitive market, indexed by $j \in [0, 1]$. Each intermediate goods firm produces a different type of intermediate good $y_t(j)$, following the Cobb-Douglas production function:

$$y_t(j) = k_t(j)^{\theta} l_t(j)^{1-\theta} - \Delta, \tag{4}$$

where z_t is total factor productivity, $k_t(j)$ is capital, $l_t(j)$ is effective labor, θ is capital income share, and $\Delta \geq 0$ is the fixed cost of production. Capital is assumed to depreciate at rate of δ each period.

The cost-minimization problem and the same factor prices that the firms face imply that they all have the same capital-labor ratio and real marginal cost, ϕ_t:

$$\tfrac{k_t(j)}{l_t(j)} = \tfrac{\theta}{1-\theta} \tfrac{w_t}{r_t^a+\delta},$$

$$\phi_t = \Xi \left(r_t^a + \delta\right)^{\theta} {w_t}^{1-\theta},$$

where $\Xi = (1-\theta)^{\theta-1}\theta^{-\theta}$. Nominal prices are sticky in the economy. Nominal price adjustment is subject to a Rotemberg (1982)'s price setting mechanism: each intermediate goods firm, j, faces costs of adjusting price. An intermediate goods firm, j, chooses its price, $p_t(j)$, to maximize expected discounted profits:

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

subject to

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

where $\Lambda_{t,t+k}$ is stochastic discount factor between t and $t+k$, $\overline{\Pi}$ is the steady-state gross inflation, and the parameter, $\Theta > 0$, is the degree of nominal stickiness. The final good firm's optimization drives the demand for intermediate good, j (Equation 5).

The first-order condition associated with the optimal price along with the symmetric equilibrium condition (i.e., $p_t(j) = P_t$ and $y_t(j) = Y_t$) leads to the following New Keynesian Phillips curve:

$$1 + \frac{\Theta}{\epsilon-1} \left(\Pi_t - \overline{\Pi} \right) \Pi_t - \frac{\epsilon}{\epsilon-1} \phi_t = \frac{\Theta}{\epsilon-1} \mathbb{E}_t \left[\Lambda_{t,t+1} \left\{ \Pi_{t+1} - \overline{\Pi} \right\} \Pi_{t+1} \frac{Y_{t+1}}{Y_t} \right],$$

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

2.4 Central Bank and Government

2.4.1 Mutual Fund and Central Bank

Households in this economy do not have a portfolio choice. Instead, I assume that a representative mutual fund trades all the assets in the economy. The mutual fund is assumed to determine the price of claims based on representative stockholder's consumption, which is assumed to be aggregate consumption. Accordingly, the implied stochastic discount factor between t and $t+1$, denoted by $\Lambda_{t,t+1}$, is given by:

$$\Lambda_{t,t+1} = \beta \frac{u_c(C_{t+1})}{u_c(C_t)},$$

where $u_c(\cdot)$ is the marginal utility of consumption, and C_t is the aggregate consumption, i.e., $C_t = \int c_t(x_t, X_t) d\mu_t$.[5]

I abstract public-sector debt or cash in the economy and follow the cashless limit assumption widely used in the context of New Keynesian economies, such as Woodford (1998) and Gornemann,

[5] Gornemann, Kuester and Nakajima (2016) have a bit different assumption. They assume that the mutual fund' claims are priced based on the asset-weighted average of its shareholders' period-to-period valuation.

Kuester and Nakajima (2016) among others. The central bank sets nominal gross interest on risk-free bonds, R_t. The optimal bond investment decision of the mutual fund implies a standard Euler equation:[6]

$$\mathbb{E}_t \left[\Lambda_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right] = 1. \tag{6}$$

The central bank conducts monetary policy following a standard Taylor rule:

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

where $\phi_\pi > 1$ and $\phi_y \geq 0$ are the reaction coefficients to inflation and the output gap, and $\overline{R}$, $\overline{\Pi}$, and $\overline{Y}$ are the steady-state values of the corresponding variables. v_t is monetary policy shocks, which follow an AR(1) process in logs:

$$\ln v_{t+1} = \rho_v \ln v_t + \varepsilon^v_{t+1}, \quad \varepsilon^v_{t+1} \sim N(0, {\sigma_v}^2).$$

2.4.2 Government

Markups and profits are countercyclical in model economies of monopolistic competition with sticky prices only, which is counterfactual (e.g., Christiano, Eichenbaum and Evans (2005)). To avoid the counterfactual implications of the sticky price, I assume that the government takes all the profits from households and spends them as government consumption (Ma, 2019).[7] This means that net profit income that households earn is zero, i.e., $\varphi_t = 0$. Without loss of generality, I also assume that lump-sum taxes are also zero, i.e., $T_t = 0$. Accordingly, we have the following government budget constraint:

$$\xi_t = G_t,$$

where ξ_t is monopoly profits net of price adjustment costs, and G_t is government spending. By having this assumption, I abstract the wealth effects associated with countercyclical profits on labor supply decisions of households.

2.5 Definition of Equilibrium

A recursive competitive equilibrium is a value function $V(x, X)$, a set of prices $\{w(X), r^a(X), R(X), \Pi(X)\}$, a set of policy functions $\{c(x, X), a'(x, X), h(x, X), k_j(X), l_j(X), p_j(X), y_j(X)\}$, and a transition operator $\Gamma(X)$ such that:

[6]Equation 6 implies that the stochastic discount factor of the mutual fund affects the pricing of other assets. An unexpected change in the nominal risk-free rate under the sticky price affects the expected real rate of return, thereby affecting all other decisions in the economy.

[7]See Ma (2019) for further discussions about how the monetary policy transmission varies according to the distribution of countercyclical profits.

1. Households optimize: given $w(X)$ and $r^a(X)$, optimal decision rules $c(x,X)$, $a'(x,X)$, and $h(x,X)$ solve the value function, $V(x,X)$.

2. Intermediate goods firms optimize: given $w(X)$, $r^a(X)$, $\Lambda(X,X')$, and $P(X)$, the associated optimal decision rules are $k_j(X)$, $l_j(X)$, and $p_j(X)$.

3. Final goods firm optimizes: given a set of prices $P(X)$ and $p_j(X)$, the associated optimal decision rules are $y_j(X)$ and $Y(X)$.

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

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

6. The government runs a balanced budget: $\xi(X)=G(X)$.[8]

7. All markets clear: for all X,

   - Labor market clears: $L(X)=\int eg(h(x,X))d\mu$, where $L(X)=\int l_j(X)dj$
   - Capital market clears: $K(X)=\int ad\mu$, where $K(X)=\int k_j(X)dj$
   - Goods market clears: $Y(X)=C(X)+I(X)+G(X)+\Omega(X)$ where $Y(X)=K(X)^\theta L(X)^{1-\theta}-\Delta$, $C(X)=\int c(x,X)d\mu$, $I(X)=K'(X)-(1-\delta)K(X)$, and $\Omega(X)=\frac{\Theta}{2}(\Pi(X)-\overline{\Pi})^2Y(X)$.

8. Individual and aggregate behaviors are consistent: for all $A^0\subset\mathcal{A}$ and $E^0\subset\mathcal{E}$,

$$\mu'(A^0,E^0)=\int_{A^0,E^0}\left\{\int_{\mathcal{A},\mathcal{E}}\mathbf{1}_{a'=a'(x,X)}\Phi_e(e'|e)d\mu\right\}da'de'.$$

2.6 Calibration

In this subsection, I discuss a simple calibration procedure that is used to assign all the parameters in the economy. As is standard in the business cycle literature, a simulation period is a quarter in the model. Table 1 summarizes the parameter values used in the model economy.

Regarding estimated processes for idiosyncratic productivity shocks, existing studies in the literature consistently report that the shocks are large and persistent. I set $\rho_e=0.939$ and $\sigma_e=0.287$, following Chang, Kim and Schorfheide (2013). The borrowing limit, $\underline{b}$, is set to -1.0, which is approximately double the quarterly average earnings in the model economy.[9]

Parameter values for production are standard. The Cobb-Douglas parameter, θ, is set to 0.33, and the quarterly depreciation rate, δ, is calibrated to be 2.5 percent. Total factor productivity, z, is fixed at one. The fixed cost, Δ, is set to ensure that profits are zero in the steady state, implying that entry is ruled out. The elasticity of substitution across intermediate goods, ϵ, is chosen to be 10, and this implies that a steady-state markup is 11 percent. The Rotemberg price adjustment

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

[9] This is consistent with the empirical findings in the literature. See Chang, Kim and Schorfheide (2013) for a detailed discussion.

Table 1: PARAMETERS OF THE MODEL ECONOMY

Parameter	Value	Description	Source/Target Moments
		HOUSEHOLDS	
β	0.97435	Time discount factor	Real return to capital
$\underline{h}$	0.114	Extensive margin for hours worked	Average hours worked
λ	14.5	Disutility parameter	Employment rate
γ	1.0	Curvature parameter	See text.
ρ_e	0.939	Persistence of e shocks	Chang, Kim and Schorfheide (2013)
σ_e	0.287	Standard deviation of e shocks	Chang, Kim and Schorfheide (2013)
$\underline{b}$	-1.0	Borrowing limit	See text.
		FIRMS	
θ	0.33	Capital income share	Standard
δ	0.025	Capital depreciation rate	Standard
Δ	0.0882	Production fixed cost	Zero profit
ϵ	10	Elasticity of substitution	11% markup
Θ	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

parameter, Θ, is set to 100. With this value, firms update their price every 4 quarters on average, given the choice of the elasticity of substitution.[10]

For the monetary policy shocks, I choose $\rho_v = 0.7$ and $\sigma_v = 0.0025$.[11] Regarding the Taylor rule coefficients of inflation and output gap, I set $\phi_\pi = 1.5$ and $\phi_y = 0.25$. These are standard values in the New Keynesian literature. The deterministic gross inflation, $\overline{\Pi}$, is set to target an inflation rate of 2 percent annualized, and then the deterministic value of gross interest rate, $\overline{R}$, is chosen to satisfy Equation 6 in the steady state.[12]

There are four additional parameters to calibrate: γ, β, λ, and $\underline{h}$. The large literature has sought to estimate the curvature parameter, γ. As discussed in Chetty (2012) among others, it was conventional wisdom that an empirically reasonable value for γ falls between 0 and 0.5. However, Keane and Rogerson (2012) argue that Chetty abstracts from additional factors that would suggest higher values of the curvature parameter, γ. Rogerson and Wallenius (2013, 2016) also provide

[10] Given a Calvo parameter ϕ, the parameter for price adjustment costs, Θ, can be computed such that: $\Theta = \frac{\phi(\epsilon-1)}{(1-\phi)(1-\beta\phi)}$.

[11] Given the value of standard deviation, σ_v, the annualized size of a typical monetary policy shock is 100 basis points.

[12] A choice of a set of $\overline{\Pi}$ and $\overline{R}$, which satisfies the condition, $\overline{R} = \overline{\Pi}/\beta$, does not affect the qualitative results of the model.

evidence that values of γ are larger than the conventional micro values. For this reason, I choose $\gamma = 1$, but I will consider a case that $\gamma = 1.5$ for a counterfactual analysis.[13] Given the value of γ and the previous choices of other parameters, the time discount factor, β, the disutility parameter of working, λ, and the nonconvexity parameter, $\underline{h}$, are chosen so that quarterly return to capital is one percent (4 percent annualized), the employment rate is 70 percent, and average hours (conditional on working) are 1/3, respectively.

3 A Validation Exercise of the Benchmark Model

The main goal of this section is to examine if the benchmark model economy generates many empirical features of the heterogeneity in wealth, income, consumption, and hours worked, and it produces empirically realistic aggregate and disaggregate responses to monetary policy shocks.

3.1 Cross-sectional Distributions

In this subsection, I compare some important cross-sectional distributions of the steady-state equilibrium in the model with the U.S. data. It is particularly important for the benchmark model economy to reasonably replicate hours distributions and their transitions for the purpose of this study.

I first examine the extent to which the model economy can successfully generate distributions of time devoted to work among households. The primary source of information on hours distributions is the Panel Study of Income Dynamics (PSID), and it is based on annual measures. Accordingly, I compute hours of work in the model at the annual level as well to be consistent with the data. In both the data and the model, an employed worker is defined as a household who provided positive hours worked during the year.

Table 2 compares the Gini coefficients for both unconditional and conditional hours, income, wealth, and consumption in the U.S data to the model economy.[14] "Unconditional hours" mean hours for both employed and non-employed households while "conditional hours" mean hours conditional on working. The model does a good job of accounting for both dimensions of hours distributions. The Gini coefficient for unconditional hours is 0.39 in the PSID, which is similar to that (0.35) in the model economy. The model and the PSID exhibit similar heterogeneity in hours worked conditional on working. The Gini index of the model is 0.19, which is close to the data (0.22).

I next examine whether the model economy produces reasonable heterogeneity in wealth, income, and consumption across individual households. The income distribution in the model economy is somewhat more concentrated compared to the data: the model economy makes the income Gini index about 0.59, while it is 0.52 in the U.S. data. The model economy reasonably replicates the

[13] Chang et al. (2019) use a wide range of values of γ, going from 0.25 to 1.5, and they use the case that $\gamma = 1$ as a benchmark when reporting the various model results.

[14] I use the 1992 survey year for all data sources because this survey year falls in the midpoint of the sample period that is used by Chang, Kim and Schorfheide (2013) to estimate processes for idiosyncratic productivity shocks.

Table 2: Key Distributions

	Gini Coefficient for				
	Uncond. Hours	Cond. Hours	Income	Wealth	Consum.
U.S. Data	0.35	0.22	0.52	0.76	0.35
Model Economy	0.39	0.19	0.59	0.71	0.37

Note: Unconditional hours denote hours for both employed and non-employed households, while conditional hours denote hours conditional on being employed. Units are annual hours in the data and the model. Information for hours, income, and wealth in the data are from PSID 1984, while statistics for consumption is the Consumer Expenditures Survey (CEX) for the period of 1984.

wealth distribution of the U.S., making the wealth Gini index of 0.71, which is a bit smaller than the data (0.76). Consumption inequality is also well-reproduced by the model: the Gini index for consumption is 0.37 in the model, which is similar to the U.S. data (0.35).

3.2 Aggregate Impulse Responses

In this subsection, I discuss the responses of key aggregate variables in the benchmark model economy to monetary policy shocks. Figure 1 exhibits the effects of an expansionary one-standard-deviation (100-basis-point, annualized) monetary policy shock on aggregate variables for 20 quarters of horizon.[15] The impulse response of all the aggregate variables in the benchmark model economy look very similar to those of empirical studies in the literature such as Christiano, Eichenbaum and Evans (2005), among others. As in standard New Keynesian models, the main mechanism of an unexpected monetary expending on economic activity is through the countercyclical markups. Due to nominal price rigidity, an expansionary monetary policy shock lowers markup of intermediate goods firms. A rise in wages by 0.52 percent on impact due to an increase in labor demand allows households to devote more hours to market work: aggregate hours increase by 0.54 percent on impact. A rise in hours worked increases output: output rises by 0.43 percent after an unexpected monetary expending. A fall in the real interest rate for risk-free bonds along with a rise in the real asset return leads households to increase their consumption and accumulate more assets. Therefore, consumption and investment rise by 0.13 and 4.3 percent, respectively. Finally, an expansionary one-standard-deviation monetary policy shock increases annualized inflation by 0.67 percent point.

3.3 Hours Response Decomposition: Extensive and Intensive Margins

Is the intensive margin not important for accounting the total hours response to a monetary policy shock? This is the question that I address in this subsection. An important feature of a nonlinear mapping from hours into efficiency units is that the model economy can generate adjustment along both intensive and extensive margins. In order to examine the contributions of each margin to the total hours response, I further split the response of total hours worked into the two margins.

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

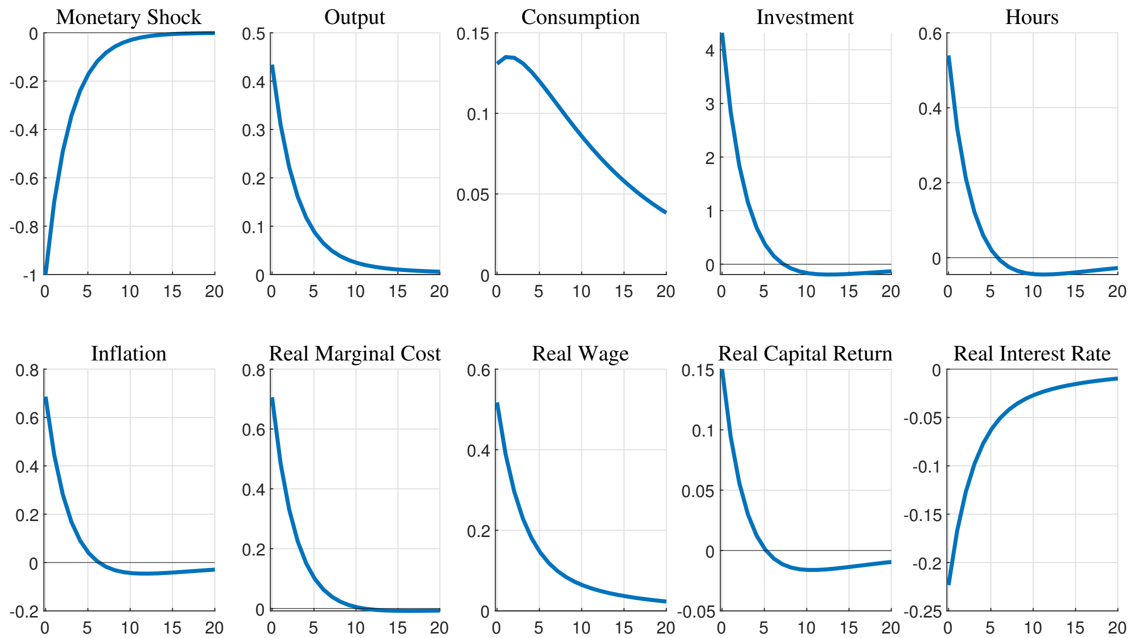

Figure 1: Impulse Responses of Aggregate Variables

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.

Figure 2 decomposes the response of aggregate hours into the extensive margin (employment) and the intensive margin (average hours conditional on working) in the benchmark model economy. As shown in Figure 2, the increased total hours are mainly due to a rise in employment, but the response of intensive margin adjustment is not small: employment rises by 0.33 percent, while average hours conditional on working increase by 0.22 percent. Having the 0.55 percent rise in total hours, the extensive margin contributes around 60 percent to the total hours response, while the intensive margin accounts for the rest (40 percent). Therefore, the employment response is relatively important, but the response along the intensive margin plays a non-negligible role in accounting for the total hours response.

I next provide empirical evidence for the effects of monetary policy shocks on both extensive and intensive margins. Toward this end, I employ a proxy Vector Autoregressive (VAR). The key idea of the proxy VAR is that the external instruments are noisy information of the true shock.[16] This method incorporates external information, such as series based on narrative evidence (e.g., Mertens and Ravn (2013)) or high-frequency data (e.g., Gertler and Karadi (2015)).[17]

To investigate the results using the proxy VAR, I use monthly measures for monetary policy shocks, developed by Romer and Romer (2004), as an external instrument. Regarding the extensive margin, I use series of the number of total employees and of average weekly hours as measures for

[16]See Ramey (2016) for a detailed discussion of the proxy VAR and its applications.

[17]Gertler and Karadi (2015) incorporates high-frequency series into the proxy VAR to identify the monetary policy shocks, and Mertens and Ravn (2013) use the narrative tax shock series, developed by Romer and Romer (2010), as an external instrument to identify the structural tax shock.

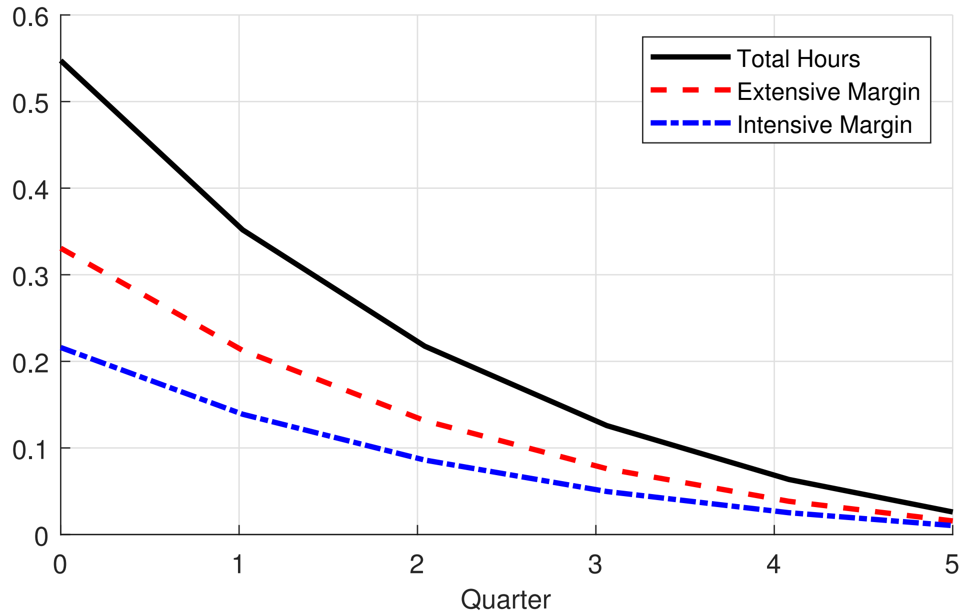

Figure 2: Decomposition of Hours Response: Extensive and Intensive Margins
Note: Impulse response to a 100-basis-point (annualized) monetary policy shock. The y axis shows percent changes, and the x-axis shows quarters after the shock.

the intensive margin. Both measures are monthly data spanning 1983 to 2007 and come from the Current Employment Statistics (Establishment Survey). Federal funds rates are ordered first, and employment, total hours or average hours and the Consumer Price Index (CPI) are ordered after the federal funds rates.[18]

Figure 3 exhibits the estimated impulse responses with an expansionary monetary policy shock.[19] The left panel depicts the total hours response, the response of employment (the extensive margin) is shown in the middle panel, and the right panel shows the response of average hours (the intensive margin).[20] Both margins tend to increase with a monetary expanding, which makes total hours peak at 0.9 percent by 13 months after the shock. The response of the extensive margin shows an inverted-U shape: the employment rises and then recovers after 2 years. The peak response of employment is around 0.8 percent. Interestingly, the response of average hours is not small. The intensive margin jumps up on impact and has a peak response of around 0.4 percent by 12 months after the shock. It is instructive to inspect how much each margin contributes to the total hours response based on the empirical impulse responses. I decompose the total margin into the two margins at the peak of the total hours response (13 months after the shock). It follows that the relative contribution of each margin is similar to what the model generates: the employment response accounts for around 55 percent of the total hours response, while the contribution of the average hours response is around 45 percent. Therefore, this empirical result supports the model

[18]The results are robust to the ordering of variables.

[19]Total hours and average hours cannot be included in the system at the same time, since the total hours worked are defined by the number of employees multiplied by average hours. Constant terms and twelve lags are included in the estimation system.

[20]I smooth the impulse-response functions based on centered moving averages with three periods.

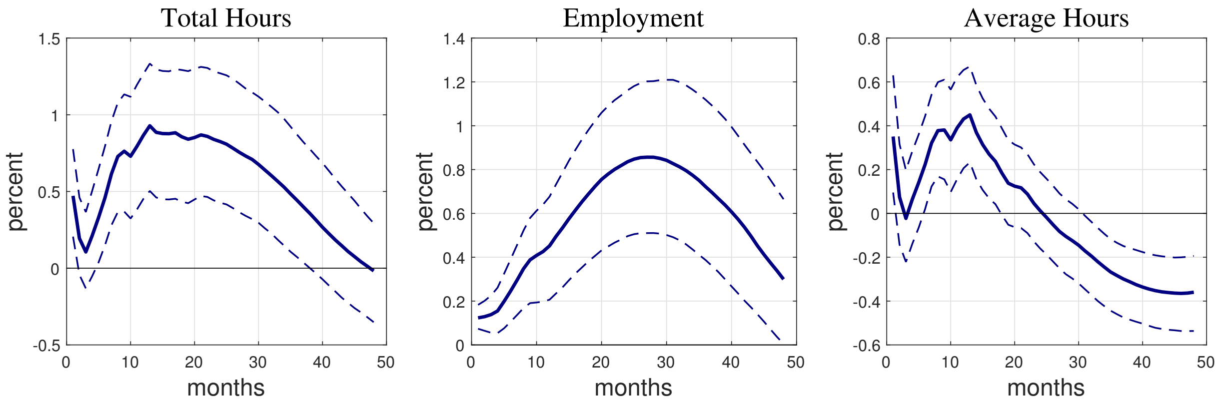

Figure 3: Decomposition of Hours Response: Proxy VAR

Note: The y axis shows percent changes, and the x-axis shows months after the shock. The shaded regions are the 68 percent confidence bands generated by Monte Carlo simulations.

prediction that the extensive margin mainly accounts for a rise in total hours, but the intensive margin response is not negligible. In other words, abstracting from the intensive margin is a not harmless simplification for understanding the aggregate hours response.

3.4 Effect of Monetary Policy on Inequality

Before jumping into further discussion, it is also important to see how monetary policy affects various measures of inequality in the benchmark economy. A rich heterogeneity in earnings, asset holdings, and income across households predicts that monetary policy shocks could have non-negligible effects on inequality in the benchmark economy. Figure 4 confirms this prediction. The effects of 100-basis-point (annualized) expansionary monetary policy shocks on the Gini coefficients of earnings, income, consumption, and wealth are reported in Figure 4. As shown in the figure, an expansionary monetary policy reduces overall inequality in the economy: the Gini coefficients of earnings, income, and consumption decrease by 0.29, 0.13, and 0.03 percent, respectively. The wealth Gini does not respond on impact, but it decreases slowly after a monetary policy shock: the Gini coefficient of wealth falls by 0.03 percent by 6 quarters after the shock.[21]

These model results are broadly consistent with the empirical literature such as that from Coibion et al. (2017) and Furceri, Loungani and Zdzienicka (2018). In particular, Coibion et al. (2017) find that the effect of a monetary policy shock on earnings inequality is less than that on total income inequality, which is well-predicted by the benchmark economy.

From various analyses in this section, I can conclude that the benchmark economy can successfully replicate the salient features of cross-sectional heterogeneity in hours worked, the movement between employment states, and the transitions within the hours distributions, along with reasonable income, wealth, and consumption distributions. The model economy also produces empirically realistic aggregate and disaggregate responses, including adjustment along both intensive and ex-

[21] As found in Ma (2019), the main mechanism of the effects of monetary policy on inequality is through a large increase in employment from the bottom of the distribution.

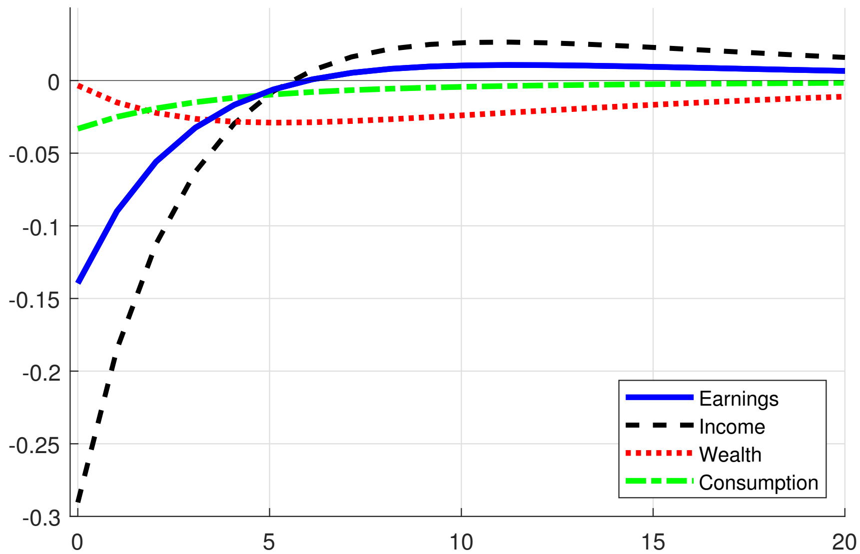

Figure 4: Responses of Inequality to Monetary Policy

Note: Impulse response of Gini coefficients of income, earnings, wealth, and consumption to a 100-basis-point (annualized) monetary policy shock. The Gini coefficients are logged, so the responses are percentage deviations from the steady state. The y axis shows percent changes, and the x-axis shows quarters after the shock.

tensive margins, to a monetary policy shock.

4 Role of Each Margin

Having assessed the benchmark model's ability to account for distributions and aggregate responses in the data, I next examine how adjustment along both intensive and extensive margins influences aggregate and disaggregate impacts of monetary policy. There are two underlying primitives in the model economy which affect the aggregate hours response in this economy: the extent of heterogeneity, σ_e, and curvature in preferences over hours of work, γ. Intuitively, the response along the extensive margin is decreasing in the degree of heterogeneity, while the response along the intensive margin is increasing in the value of the preference parameter.

There are many reasonable estimates for these two parameters. However, different combinations in that space can have profound implications for the economic response to a monetary policy shock even when the aggregate hours response is identical. Accordingly, I consider two counterfactual economies with the different extent of heterogeneity and a different curvature parameter, respectively, where both model economies are calibrated to generate the same response of total hours to a standardized monetary policy shock. Specifically, for one specification, I set $\gamma = 1.5$ keeping σ_e the same as that in the benchmark model, dented by the "LG model," which stands for "Larger Gamma." For the other specification, having the same γ as in the benchmark model, I choose $\sigma_e = 0.197$ so that the on-impact response of total hours to a monetary policy shock is the same as that in the LG economy. I denote this economy as the "SH model," which stands for "Smaller Heterogeneity." As in the benchmark model, the two specifications are also calibrated to produce the same employment rate of 70 percent and the same average hours for workers conditional on

Table 3: Distribution of Hours for Three Models

	Gini for Unconditional Hours	Gini for Conditional Hours
Benchmark	0.35	0.19
Smaller σ_e	0.34	0.18
Larger γ	0.38	0.22

Note: "Benchmark" denotes the benchmark model where $\sigma_e = 0.287$ and $\gamma = 1.0$. "Smaller σ_e" denotes the model where $\sigma_e = 0.197$ and $\gamma = 1.0$. "Larger γ" denotes the model where $\sigma_e = 0.287$ and $\gamma = 1.5$. Unconditional hours denote hours for both employed and non-employed households, while conditional hours denote hours conditional on being employed. Units are annual hours.

employment (one-third). It should be noted that even if the two counterfactual economies have the same on-impact response of total hours, the relative size of each margin is different. In the LG model economy, the intensive margin is the dominant margin of adjustment, while the extensive margin will be relatively important in accounting for the response of total hours in the SH model economy.[22]

4.1 Aggregate Implications

This subsection addresses an important question: what role does each margin play in accounting for aggregate effects of monetary policy? Before comparing aggregate responses of the model economies, I examine how annual hours distribution varies across the three model specifications in Table 3. The hours dispersion in the LG model is relatively large: the Gini coefficients for total hours (unconditional on employment) and hours conditional on employment are 0.38 and 0.22, respectively, in the LG economy, while the corresponding values are 0.35 and 0.19, respectively, in the benchmark model. Consistent with intuition, there is a negative relation between the standard deviation of the idiosyncratic shocks and the cross-sectional dispersion in hours worked. In the SH economy, the Gini index for total hours is 0.34, and the Gini coefficient for hours conditional on working is 0.18. Both measures in the SH economy are smaller than those in the benchmark model.

I next discuss how effects of monetary policy vary across the three model economies. Figure 5 shows the responses of key macro variables to monetary policy shocks in three model economies: the benchmark, the SH and the LG economies. As noted earlier, the response of total hours in the two counterfactual economies are the same by construction. As shown in the upper row in Figure 5, the responses of total hours in both of the SH and LG economies are larger than that in the benchmark economy: total hours increase by 0.58 percent in both counterfactual economies, while it rises by 0.54 in the benchmark case. While both counterfactual economies produce the same size of the total hours response, there is a compositional difference. In the economy with smaller σ_e, the contribution of the extensive margin to the total hours response increases. The response of employment in the model with smaller σ_e increases to 0.4 percent (from the 0.33 percent in the benchmark economy),

[22] Either way, the response of total hours will be larger than the benchmark economy. In the SH economy, aggregate labor supply elasticity will be large since relatively many marginal workers are placed around the market wage when the economy is less heterogeneous. See Rogerson and Wallenius (2009), Chang and Kim (2006), and Ma (2019) for detailed discussions.

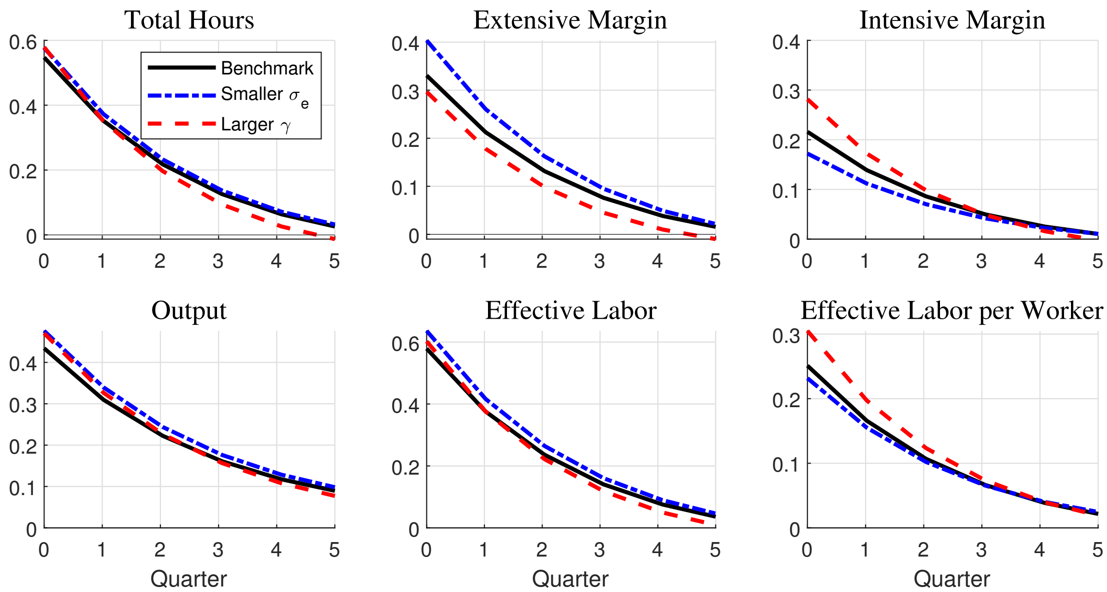

Figure 5: Comparison across Model Economies I

Note: Impulse response to a 100-basis-point (annualized) monetary policy shock. The y axis shows percent changes, and the x-axis shows quarters after the shock. "Benchmark" denotes the benchmark model where $\sigma_e = 0.287$ and $\gamma = 1.0$. "Smaller σ_e" denotes the model where $\sigma_e = 0.197$ and $\gamma = 1.0$. "Larger γ" denotes the model where $\sigma_e = 0.287$ and $\gamma = 1.5$.

but the average hours response decreases to 0.17 percent (from the 0.22 percent in the benchmark economy). This composition change makes the extensive margin account for 70 percent of the total hours response, while it contributes 60 percent to the total hours response in the benchmark model. The opposite result comes in the economy with a higher value of the curvature parameter, γ. In the LG model, the intensive margin response increases to 0.28 percent, and the response along the extensive margin slightly decreases, compared to the benchmark economy.[23] Accordingly, the contribution of the average hours response in the economy with larger γ is around 49 percent, which is larger than the 40 percent in the benchmark economy.

The analysis in this subsection provides an important message to the conventional view regarding the total hours response. Even if the two economies generate the same response of total hours worked, they have totally different underlying behaviors (different responses of both intensive and extensive margins) as well as the different steady-state properties (different distributions of hours and income). This finding is of immediate relevance to monetary policymakers since understanding and quantifying the sources of aggregate responses is important to determine most appropriate policies.

Another important aggregate implication is the response of efficiency units of labor. This dimension is important to understand the response of output since it is the effective labor that is in the production function as in Equation 4, not aggregate hours. The bottom row in Figure 5 compares the responses of output, efficiency units of labor (effective labor), and effective labor per employed

[23]General equilibrium effects induced by consumption and wage responses can explain the smaller response of average hours in the SH economy and of employment in the LG model than those in the benchmark economy. I will discuss this issue in detail later.

households in the three economies. An important finding is that the two counterfactual economies have different compositional effects in response to a monetary policy shock. Specifically, starting from the bottom-right panel in Figure 5, the response of effective labor per working households increases in the economy with larger γ, where the intensive margin is dominant, by more than that in the benchmark economy. Efficiency units of labor per employed households increase by 0.30 percent in the economy with larger γ, while it rises by 0.25 percent in the benchmark case. Recalling that the size of the employment response is smaller in this counterfactual economy than that in the benchmark model, this implies that relatively productive households work more in the model with larger γ. In contrast, efficiency units of labor per employed households in the SH economy increase only by 0.23 percent, which is smaller than that in the benchmark model economy. Given the large increased employment in the economy with smaller σ_e, relative to the benchmark economy, this implies that relatively less productive households work more in the model with smaller σ_e. Overall, due to the larger employment effects, the response of efficiency units of labor is a bit larger in the SH model than that in the LG model, which makes the output response also a bit larger. This finding offers an interesting implication for the disaggregate effects of monetary policy: the distributional consequences of monetary policy may depend on the relative size of adjustment along the intensive and extensive margin. I will discuss this issue in detail later.

4.2 Disaggregate Implications

I next examine distributional implications of adjustment along both intensive and extensive margins. This analysis also provides an important message to monetary policy makers in the sense that, as discussed by Coibion et al. (2017) and Kaplan, Moll and Violante (2018), understanding of the monetary transmission mechanism at the disaggregate level is particularly important for the successful conduct of monetary policy.

One may argue that the extent to which margin of labor supply is dominant may not be the first-order issue since the two counterfactual economies (the LG and SH economies) generate the very similar responses of hours and output. In this subsection, I challenge this view and argue that the relative size of each margin is significantly important for accounting for the distributional effects of monetary policy. This is the main focus in this paper.

As briefly discussed earlier, two findings, which are related to the distributional consequences of monetary policy, emerge from Figure 5. First, in the SH economy, the employment response is relatively large, and relatively less productive households work more. Second, in the LG economy, the response of employment is less than that in the benchmark economy, and households with relatively high productivity increase their hours by more. These two findings imply that monetary policy generates substantially different effects on inequality, particularly earnings inequality, in the two counterfactual economies. Intuitively, in the SH economy, expansionary monetary policy may decrease earnings inequality by more due to a significant rise in employment from the bottom of the distribution, while earnings inequality may decrease by less or may increase in the LG economy since relatively productive households work more.

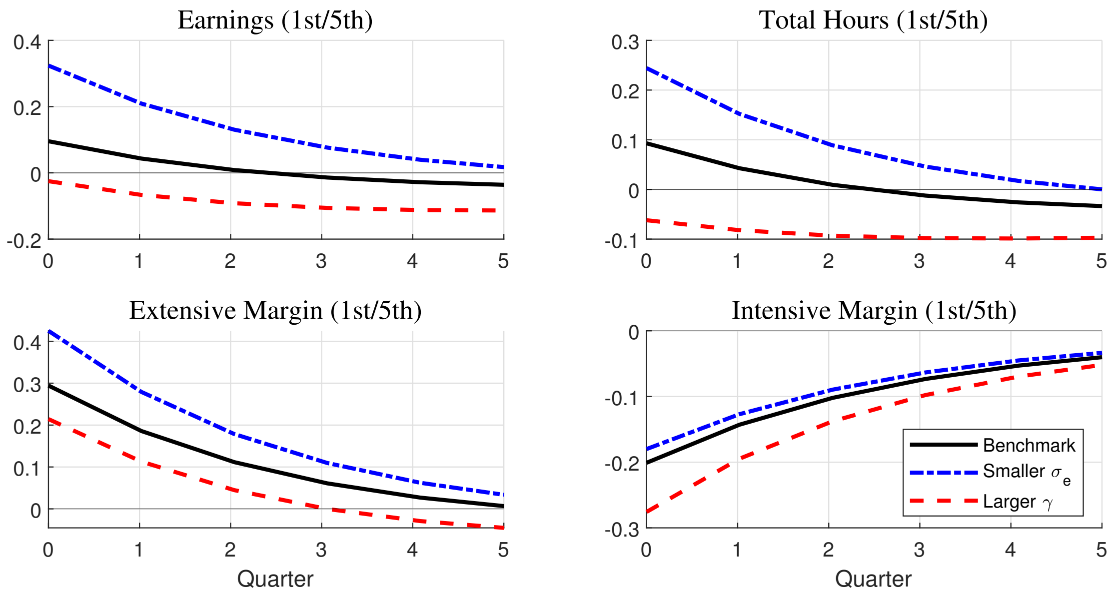

Figure 6: Comparison across Model Economies II

Note: Responses of earnings, total hours, the extensive margin, and the intensive margin for the lowest productivity quintile (1st quintile) relative to the highest productivity quintile (5th quintile). The y axis shows percent changes, and the x-axis shows quarters after the shock. "Benchmark" denotes the benchmark model where $\sigma_e = 0.287$ and $\gamma = 1.0$. "Smaller σ_e" denotes the model where $\sigma_e = 0.197$ and $\gamma = 1.0$. "Larger γ" denotes the model where $\sigma_e = 0.287$ and $\gamma = 1.5$.

To better understand how the relative size of adjustment along the intensive and extensive margin plays a role in distributional effects of monetary policy, it is instructive to inspect the responses of hours-related variables depending on the level of productivity. Figure 6 compares the responses of earnings, total hours, the extensive margin (employment), and the intensive margin (average hours) across three model economies (the benchmark, the SH and LG economies). All the responses in Figure 6 show the responses of the lowest productivity quintile (1st quintile) relative to the highest productivity quintile (5th quintile).

As Figure 6 reveals, the distributional effects of monetary policy are substantially different between the two counterfactual economies, implying that the disaggregate effects depend on the relative size of adjustment along the intensive and extensive margin. The upper left panel in Figure 6 exhibits that the effect of monetary policy on earnings inequality is larger in the SH economy than that in the benchmark model. In response to an expansionary monetary policy shock, earnings for the first quintile relative to the fifth quintile increase by around 0.3 percent in the economy with smaller heterogeneity, while the relative earnings rise by only 0.1 percent in the benchmark economy. This result is interesting in the sense that a more equal economy has a more effective monetary policy in terms of both output (See Figure 5) and earnings inequality responses.[24] As reported in the bottom left panel of Figure 6, this is mainly due to a significant rise in employment from the bottom of the productivity distribution in the SH economy: the relative employment response (1st/5th) is 0.43 percent in the economy with smaller heterogeneity, while it is only 0.29 percent

[24]See Ma (2019) for a detailed discussion about the relation between monetary policy effectiveness and inequality.

in the benchmark economy.[25] The large increase in employment of households at the bottom of the productivity distribution in the SH economy leads to a large increase in the relative total hours (1st/5th) as shown in the upper right panel of Figure 6.[26]

Another interesting finding is that the response of relative earnings (1st/5th) is negative on impact in the LG economy, as shown in the upper left panel of Figure 6, while it is positive on impact in other two economies (the benchmark and SH economies). This implies that monetary expanding increases earnings inequality when the intensive margin is the dominant source of variations in total hours worked. A rise in earnings inequality in the LG economy mainly comes from a larger increase in average hours provided by relatively productive households, as reported in the bottom right panel of Figure 6. The response of average hours for the first productivity quintile relative to the fifth group decreases by more in the LG economy than that in the benchmark model: the relative average hours fall by 0.28 percent in the LG economy, while they decrease by 0.2 percent in the benchmark case. This large decrease in the relative average hours in the LG economy leads to a fall in the relative total hours (1st/5th) as shown in the upper right panel of Figure 6 even though the relative employment (1st/5th) response is still positive (See the bottom left panel of Figure 6).

Therefore, the two counterfactual economies have significantly different distributional effects on earnings inequality from both quantitative and qualitative perspectives even though they generate the quite similar responses of output and total hours (See Figure 5). Hence, the extent to which margin of labor supply is dominant is crucial for accounting for the effects of monetary policy on the distribution of earnings.

5 Discussions

5.1 Hump-shaped Employment Response

As shown in Figure 3, the empirical impulse responses of employment and average hours to a monetary policy shock are different in shape. The response of employment is hump-shaped and reaches a trough in two years after the shock while the response of average hours peaks earlier (one year after the shock). In this subsection, I discuss a model feature that can replicate the empirical impulse responses of employment and average hours. To generate the hump-shaped employment response, I follow Dossche, Gazzani and Lewis (2022) and consider employment adjustment costs.[27] Specifically, I assume that each intermediate goods firm faces employment adjustment costs, $J(E_t, E_{t-1})$, such that

[25]The different responses of employment between productive and less-productive households are broadly consistent with an empirical finding in Ma (2019). Based on micro-level data, Ma (2019) finds that employment of the poor increases, while richer households do not change their employment in response to a monetary expansion.

[26]The intensive margin response of the lowest quintile relative to the highest group in the SH economy is somewhat larger than that in the benchmark economy (the bottom right panel of Figure 6), which also contributes to an increase in the relative hours (1st/5th).

[27]Andolfatto (1996) has both margins of labor supply, and employment is subject to search frictions. Nakajima (2012) builds an incomplete-market version of the model with both margins of labor supply adjustment.

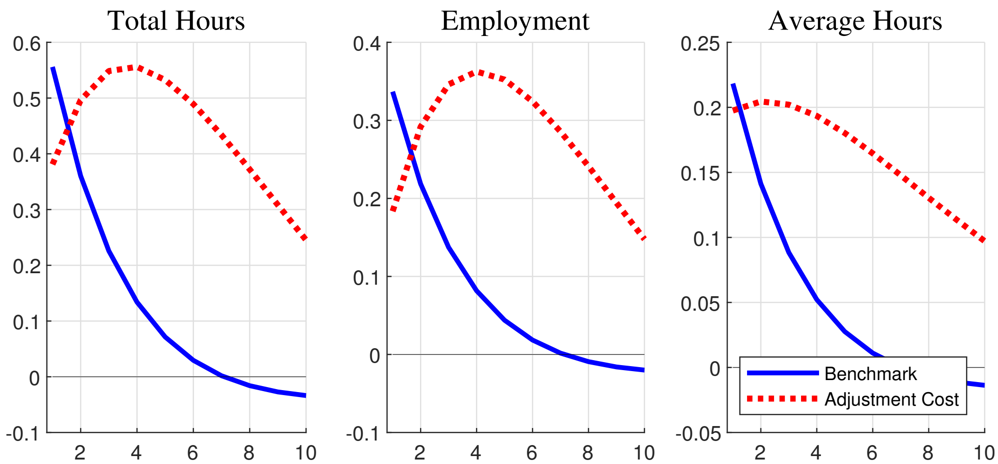

Figure 7: Role of Employment Adjustment Costs
Note: Responses of total hours, employment (the extensive margin), and average hours (the intensive margin) for the benchmark model and the model with employment adjustment costs.

$$J(E_t, E_{t-1}) = \frac{\kappa}{2}\left(\frac{E_t}{E_{t-1}} - 1\right)^2 E_t, \tag{8}$$

where E_t is total employment at time t, and κ is the size of the adjustment cost. The first order condition with respect to employment is:

$$\frac{(1-\theta)K_t^{\theta}L_t^{1-\theta}}{E_t} + \kappa\left(\frac{E_t}{E_{t-1}} - 1\right)\frac{E_t}{E_{t-1}} + \frac{\kappa}{2}\left(\frac{E_t}{E_{t-1}} - 1\right)^2 - \kappa\mathbb{E}_t\left[\Lambda_{t,t+1}\left(\frac{E_{t+1}}{E_t} - 1\right)\left(\frac{E_{t+1}}{E_t}\right)^2\right] = \frac{w_t L_t}{E_t\phi_t}. \tag{9}$$

Equation 9 implies that the marginal product of employment on the left hand side equals the marginal cost of employment, i.e., the wage per worker, $\frac{w_t L_t}{E_t}$, divided by the real marginal cost, ϕ_t.[28] It should be noted that the change in the firm's employment gives rise to the adjustment cost in the current period, and the next period's employment adjustment cost which depends on current employment also enters the first-order condition.

Figure 7 compares the responses of total hours, employment (the extensive margin), and average hours (the intensive margin) for the benchmark model and the model with employment adjustment costs.[29] I choose κ so that total hours in the economy with the employment adjustment cost have a peak response in four quarters after the shock, as observed in Figure 3.[30] According to Figure 7, employment adjustment frictions discourage hours adjustment along the extensive margin on impact: the on-impact employment response is around 0.2 percent, which is much smaller than

[28] Notice that if there is no employment adjustment costs, i.e., $\kappa = 0$, then the marginal product of effective labor, $(1-\theta)\left(\frac{K_t}{L_t}\right)^{\theta}$ equals the marginal cost of effective labor, $\frac{w_t}{\phi_t}$.

[29] For comparison, I keep the peak responses of total hours in the two economies the same.

[30] The results are robust to different values of κ from a qualitative perspective.

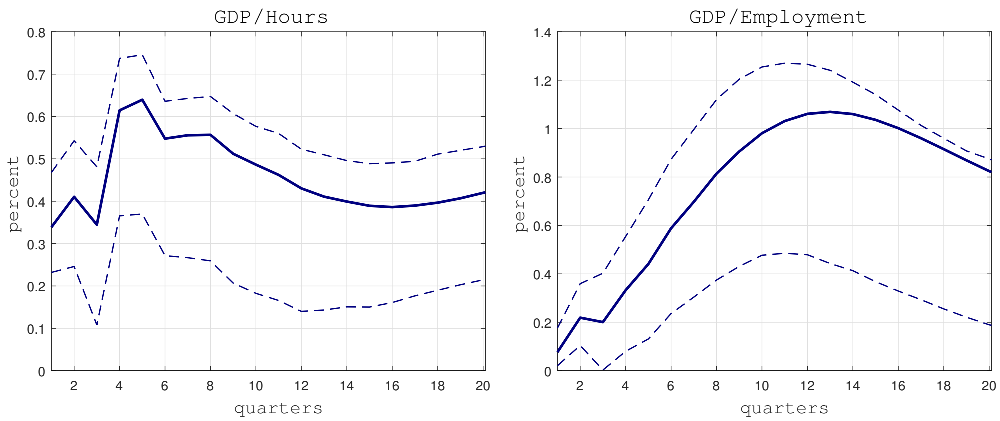

Figure 8: Response of Average Labor Productivity
Note: Responses of average labor productivity where the average productivity is measured by GDP divided by total hours (left panel) and by GDP divided by employment (right panel).

that in the benchmark economy (0.33 percent). Importantly, in the economy with employment adjustment costs, employment slowly adjusts and has a hump-shaped response: employment peaks at 0.35 percent in four quarters after the shock. However, the response of average hours peaks earlier (2 quarters after the shock) than employment.[31] Therefore, employment adjustment costs help replicate the empirical impulse responses of employment and average hours from a qualitative perspective. It should also be noted that in the presence of the employment adjustment cost, the contribution rate of the extensive margin to the total hours response is around 63 percent, while the intensive margin accounts for 37 percent. This is consistent with the result found in the benchmark economy.

5.2 Response of Average Productivity

Do the hours increase among high productivity workers when there is an expansionary monetary policy shock? This is an important question since it is highly related to the earnings distribution response to monetary policy shocks, as discussed above. However, it is not an easy task to empirically document this question since micro-level data are not available at higher frequencies. Instead, I empirically show how average labor productivity responds to a monetary policy shock. This should include some information about what kind of workers are working longer hours in response to a monetary policy shock.

Figure 8 shows the responses of average labor productivity to expansionary monetary policy shocks where the average productivity is measured by GDP divided by total hours (the left panel) and by GDP divided by employment (the right panel).[32] Regardless of which productivity measure is used, average labor productivity increases after an unexpected monetary easing. This may imply that more productive households work longer hours in response to an expansionary monetary policy

[31] The response of average hours is also hump-shaped since the real wage response is hump-shaped (not shown in the figure).

[32] A proxy VAR is used where federal funds rates are ordered first, total hours (or employment), GDP, and CPI are ordered next.

shock.

6 Conclusion

In this paper, I study how adjustment along the intensive and extensive margins affects aggregate and disaggregate effects of monetary policy. To this end, I develop a New Keynesian economy with heterogeneous agents where a nonlinear mapping from time devoted to work to labor services generates operative intensive and extensive margins of labor supply. The model economy can produce reasonable cross-sectional heterogeneity and successfully replicate responses of aggregate variables, including adjustment along both intensive and extensive margins, to a monetary policy shock.

The main finding is that, even if two economies generate similar aggregate implications of monetary policy, they may have significantly different disaggregate effects, depending on the relative size of adjustment along the intensive and extensive margins. In response to an expansionary monetary shock, earnings inequality decreases substantially when the extensive margin is the dominant margin of adjustment, while it may increase in an economy with larger intensive margin adjustment. Therefore, the extent to which margin of labor supply is dominant is crucial for explaining the distributional consequences of monetary policy.

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Appendix: The Computational Algorithm

A Steady-state Economy

The computational algorithm used for the steady-state economy is summarized. In this step, I find the stationary measure, $\overline{\mu}$. The steps are as follows.

Step 1. Endogenous parameters such as β and λ are selected.

Step 2. Construct grids for as asset holdings, a and logged individual labor productivity, $\hat{e} = \ln e$, where the number of grids for a and $\widehat{e}$ are denoted by N_a and N_e, respectively. I set $N_a = 201$ and $N_e = 17$. a falls in the rage of $[-1, 200]$. More asset grid points are assigned on the lower values of a. $\widehat{e}$ is equally spaced in the range of $[-3\sigma_{\hat{e}}, 3\sigma_{\hat{e}}]$, where $\sigma_{\hat{e}} = \sigma_e/\sqrt{1-\rho_e^2}$.

Step 3. Using Tauchen (1986), compute the transition probability matrices for individual labor productivity, Φ_e.

Step 4. Solve the individual Bellman equations. In this step, the optimal decision rules for saving $a'(a, e)$ and hours worked $h(a, e)$, the value functions, $V(a, e)$, are obtained. The detailed steps are as follows:

(a) Compute the steady-state real wage rate based on the firm's first-order condition, where the steady-state capital return, $\overline{r}^a$, is chosen to be 1 percent.

(b) Make an initial guess for the value function, $V_0(a, e)$ for each grid point.

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

$$V_1^E(a,e) = \max_{a' \geq \underline{b},\, h \geq \underline{h}} \Bigg\{ \ln\left(\overline{w} g(h) e + (1+\overline{r}^a)a - a'\right)$$

$$-\lambda \tfrac{h^{1+1/\gamma}}{1+1/\gamma} + \beta \sum_{e'=1}^{N_e} \Phi_e(e'|e) V_0(a', e') \Bigg\},$$

and

$$V_1^N(a,e) = \max_{a' \geq \underline{b}} \Bigg\{ \ln\left((1+\overline{r}^a)a - a'\right) + \beta \sum_{e'=1}^{N_e} \Phi_e(e'|e) V_0(a', e')\} \Bigg\}.$$

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

(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 Φ_e.

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

B Economy with Monetary Policy Shocks

I summarize the computational algorithm used for the economy with aggregate shocks. To solve the dynamic economy, the distribution across households, μ, which will affect prices, should be tracked of. Instead, I follow Krusell and Smith (1998) and use the first moment of the distribution and the forecasting function for it. The steps are as follows.

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

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

Step 4. Given the forecasting functions for K' and w, I solve the optimization problems for the individual households.[33] I solve the optimization problems for households and obtain the policy functions for asset holdings, $a'(a, e, K, v)$, and consumption $c(a, e, K, v)$, and the hours decision rule, $h(a, e, K, v)$.[34]

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 $\mu(a, e)$.

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

(c) Obtain the market-clearing wage, w. I choose $\widetilde{w}$ as a guess for w. Given the forecasting functions and the evaluated value function obtained in Step 4, I obtain the hours decision rule, $h(a, e)$. I check if the labor supply is equal to labor demand, i.e., $L = \int eg(h(a, e))d\mu = L^D$.[35] If not, update $\widetilde{w}$.

[33] Given the wage rate, w, and the marginal cost, ϕ, the real interest rate, r^a, can be obtained from the firm's profit maximization.

[34] As in the steady-state economy, the transition probabilities for e and v are approximated using Tauchen (1986).

[35] Given the wage rate, $\widetilde{w}$, and the marginal cost, ϕ, labor demand, L^D, can be obtained from the firm's first order condition.

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

(e) I obtain aggregate variables based on the type distribution, μ, where $C = \int c(a,e)d\mu$, $L = \int eg(h(a,e))d\mu$, $K' = \int a'(a,e)d\mu$, $H = \int h(a,e)d\mu$, $Y = K^{\theta}L^{(1-\theta)} - \Delta$, and $I = K' - (1-\delta)K$.

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

Step 6. I obtain the new coefficients for the forecasting functions by the OLS estimation using the simulated time series.[36] 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.

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