Labor-Market Heterogeneity and the Lucas Critique

Yongsung Chang
University of Rochester
Yonsei University

Sun-Bin Kim
Yonsei University

Frank Schorfheide *
University of Pennsylvania
CEPR and NBER

April 29, 2010

Abstract

Representative agent dynamic stochastic general equilibrium (DSGE) models are widely used to analyze the effects of economic policy changes. A key assumption in policy experiments is that taste and technology parameters as well as structural shocks are policy invariant. We construct a heterogeneous agent economy in which equilibrium outcomes depend on the distributions of wealth and earnings because households face uninsurable idiosyncratic productivity shocks. We estimate a representative-agent DSGE model that approximates the aggregate times series generated from the underlying heterogeneous agent model. We find (i) that the aggregation error is captured by preference shocks in the representative agent model; (ii) taste and technology parameters in the DSGE model are not policy invariant; (iii) fiscal policy predictions from the DSGE model are often inaccurate. (JEL: C11, C32, E32, E62)

KEY WORDS: Aggregation, Fiscal Policy Analysis, Heterogeneous Agents Economy, Lucas Critique, Representative Agent Models.

---

*Correspondence: Y. Chang: Department of Economics, University of Rochester, Harkness Hall, Rochester, NY 14627. Email: yongsung.chang@rochester.edu. S.B. Kim: Yonsei University, College of Business and Economics, 262 Seongsanno, Seodaemun-Gu, Seoul 12-749, South Korea. Email: sunbink@yonsei.ac.kr. F. Schorfheide, Department of Economics, University of Pennsylvania, 3718 Locust Walk, Philadelphia, PA 19104. schorf@ssc.upenn.edu. We thank participants at various seminars for helpful comments. Schorfheide gratefully acknowledges financial support from the National Science Foundation under Grant SES 0617803.

1 Introduction

The Lucas critique of econometric policy evaluation (1976) argues that if econometric models do not capture the primitive parameters of preferences and technology, their coefficients can be expected to vary with changes in policy regimes. The empirical work inspired by the Lucas critique has proceeded by replacing econometric models which were parameterized in terms of agents' decision rules with models in which parameters characterize the objective functions and constraints faced by representative economic agents. With these "deep" parameters in hand, it is possible to re-derive agents' decision rules under alternative economic policies. In recent years, dynamic stochastic general equilibrium (DSGE) models based on the work of Smets and Wouters (2003) and Christiano, Eichenbaum, and Evans (2005) have been widely used to study the effects of monetary and fiscal policy changes. The core of these DSGE models is comprised of a neoclassical stochastic growth model, pioneered by Kydland and Prescott (1982).

The tacit assumption underlying the DSGE model-based policy analysis has been that the parameters that characterize the preferences of a representative agent and the production technologies of a representative firm as well as the exogenous structural shocks that generate business cycle fluctuations are policy invariant. However, to the extent that macroeconomic time series on variables such as output, consumption, investment, and hours worked are constructed by aggregating across heterogeneous households and firms, the assumption of policy invariance is not self-evident. More than two decades ago, Geweke (1985, p.206) pointed out, while the treatment of expectations and dynamic optimization has been careful, potential problems due to aggregation have usually been ignored: *"Whenever econometric policy evaluation is undertaken using models estimated with aggregated data, it is implicitly presumed that the aggregator function is structural with respect to the policy intervention."*

The goal of this paper is to assess the quantitative importance of biases in policy predictions due to the potential lack of invariance of taste and technology parameters as well as shock processes in representative agent models. As a laboratory model we are using a heterogeneous agent economy in which households have to insure themselves against idiosyncratic income risks. The model economy features incomplete asset markets and household face a constraint on the amount they can borrow (Bewley, 1983; Huggett, 1993; and Aiyagari, 1994). Moreover, households supply their labor in an indivisible manner (Rogerson, 1988).[1]

In this environment the distribution of household wealth and productivity is important for aggregate outcomes. The heterogeneous agent model economy is calibrated to match the cross-sectional distribution of wealth and earnings in the U.S. We simulate this economy with aggregate productivity shock that is comparable to the time series of measured aggregate TFP in the data. Using the aggregate times series on output, consumption, wages, and hours worked generated from the heterogeneous agent model, we estimate a representative agent DSGE model with state-of-the-art Bayesian methods (Schorfheide, 2000; An and Schorfheide, 2007) and examine the potential lack of policy invariance of the DSGE model parameters. It turns out, using Geweke's expression, that the aggregator is not invariant to policy changes. For example, the aggregate labor supply elasticity depends on the cross-sectional distribution of reservation wages, which in turn is a function of the fiscal policy regime. Such dependence of aggregator on the policy regime is quantitatively large enough to lead us to make predictions outside a reasonable confidence interval.

In our model economy the heterogeneity is concentrated on the household side. Since the wealth distribution of households is more sensitive to fiscal rather than monetary policy, we focus on changes in tax rates and the composition of government spending to examine the importance of aggregation biases.[2] The quantitative analysis generates the following findings. First, the effects of aggregation manifest themselves through the presence of preference shocks in the representative agent model. Alternatively, these preference shocks can also be interpreted as wedges (Chari, Kehoe, McGrattan, 2007) in the inter and intra-temporal optimality conditions for the choice of consumption and employment. The likelihood-based estimation approach allows us to extract time series for the stochastic preference shifts. In a variance decomposition these preference shocks explain more than 50% of the variation of hours worked. Second, if the representative agent model is estimated based on data from the heterogeneous agent economy under different policy regimes, several important param-

[1] Both the theoretical and the empirical importance of these frictions are by now widely recognized. Recent examples include Krusell and Smith (1997), Chang and Kim (2006), Ljungqvist and Sargent (2007), Nakajima (2007), Krusell, Mukoyama, Rogerson, and Sahin (2008), and Rogerson and Wallenius (2009).

[2] To assess the sensitivity of DSGE model parameters to changes in monetary policy, Fernández-Villaverde, Jesús, and Rubio-Ramiréz (2007) estimate a model in which both monetary policy rule parameters and nominal rigidity parameters are allowed to vary over time. Co-movements of these two groups of parameters are interpreted as evidence against policy invariance.

eters, including the aggregate supply elasticity and the level of total factor productivity, vary considerably. Third, when trying to predict the effect of fiscal policy changes on the levels of hours, consumption, and hours, we find that the lack of policy invariance of the aggregator function is sufficiently strong to render predictions from the representative agent model inaccurate. In particular, the aggregation bias is substantially larger than prediction intervals constructed from the representative agent model that reflect parameter estimation uncertainty.

This paper is related to previous work by a subset of the coauthors. Calibrated heterogeneous agent economies similar to one in this paper have been used as laboratory for quantitative analysis in Chang and Kim (2006, 2007) and An, Chang, and Kim (2009). However, none of the three papers considers the policy invariance of the parameters in an estimated representative agent model. Chang and Kim (2006) emphasize that estimates of an aggregate labor supply elasticity are closely tied to the slope of the reservation wage distribution and find that the aggregate Frisch elasticity based on the calibrated heterogeneous agent economy should be approximately one. Chang and Kim (2007) focus on the so-called labor market wedge between the marginal product of labor and the marginal rate of substitution that arises when the aggregated data are interpreted through the lens of a representative agent model. The presence of this wedge in U.S. data is well documented, e.g. Hall (1997), and Chang and Kim (2007) find that they can reproduce some of its cyclical features with simulated data from the incomplete markets model. Other papers showing that asset market incompleteness can lead to a stochastic term in aggregate preferences include Scheinkman and Weiss (1986), Krüger and Lustig (2007), and Liu, Waggoner, and Zha (2008). Finally, An, Chang, and Kim (2009) focus on GMM-based estimates of households' first-order conditions. The apparent failure of these optimality conditions in actual data can be reproduced with simulated data and hence to a large extent attributed to aggregation rather than market failure.

The remainder of the paper is organized as follows. Section 2 lays out the heterogeneous agent economy that features incomplete capital markets and indivisible labor. We calibrate the model economy to match salient features of the cross-sectional income and wealth distribution in the U.S. as well as some key business cycle properties. Section 3 presents the representative agent DSGE model that is estimated based on simulated data from the heterogeneous agent economy and used to predict the effect of policy changes.

The quantitative results are presented in Section 4. Finally, Section 5 concludes. Detailed derivations for the representative agent model can be found in the Appendix.

2 Heterogeneous-Agent Economy

We provide a description of the heterogeneous agent economy that serves as a data generating mechanism for the quantitative analysis. The model economy is based on Chang and Kim (2006), which extends Krusell and Smith's (1998) heterogeneous agent model with incomplete capital markets (Aiyagari, 1994) to indivisible labor supply (Rogerson, 1988). This model highlights that individual optimality conditions for the choice of consumption and leisure—which holds as inequality due to discrete choice of labor supply—do not aggregate nicely.

2.1 Economic Environment

The model economy consists of a continuum (measure one) of households who have identical preferences but ex post different productivities. Household-specific productivity x_t varies exogenously according to a stochastic process with a transition probability distribution function $\pi_x(x'|x) = \Pr(x_{t+1} \leq x'|x_t = x)$. A worker maximizes his utility by choosing consumption c_t and hours worked h_t:

$$\begin{aligned} \max \quad & \mathbb{E}_t \left[\sum_{s=0}^{\infty} \beta^s \left\{ \log c_{t+s} - B \frac{h_{t+s}^{1+1/\gamma}}{1+1/\gamma} \right\} \right] \qquad (1) \\ \text{s.t.} \quad & c_t + a_{t+1} = a_t + (1-\tau_H) W_t x_t h_t + (1-\tau_K) R_t a_t + \bar{T} \\ & a_{t+1} \geq \underline{a}, \quad h_t \in \{0,\ \bar{h}\}. \end{aligned}$$

Households trade assets a_t which yield the rate of return R_t. These assets are either claims to the physical capital stock or IOUs, which are in zero net supply. Both asset types generate the same return R_t, which is subject to the capital tax τ_K.

Households face a borrowing constraint: $a_{t+1} \geq \underline{a}$. Households supply their labor in an indivisible manner, that is, h_t either takes the value 0 or $\bar{h}$. We normalize the endowment of time to one and assume $\bar{h} < 1$. If a household supplies $\bar{h}$ units of labor, the labor income is $W_t x_t \bar{h}$, where W_t is the aggregate wage rate for an efficiency unit of labor. Labor income is subject to the tax τ_H and $\bar{T}$ denotes lump-sum taxes or transfers. Ex post households differ with respect to their productivity and asset holdings. The joint distribution of x_t and a_t is characterized by the probability measure μ_t.

A representative firm produces output Y_t according to a constant-returns-to-scale Cobb-Douglas technology in capital, K_t, and efficiency units of labor, L_t.

$$Y_t = F(L_t, K_t, \lambda_t) = \lambda_t L_t^{\alpha} K_t^{1-\alpha}, \tag{2}$$

where λ_t is the aggregate productivity shock with a transition probability distribution function $\pi_\lambda(\lambda'|\lambda) = \Pr(\lambda_{t+1} \leq \lambda'|\lambda_t = \lambda)$. The representative firm's profit function is:

$$\Pi_t = Y_t - W_t L_t - (R_t + \delta)K_t. \tag{3}$$

The first-order conditions for the profit maximization are

$$W_t = \alpha Y_t / L_t \quad \text{and} \quad (R_t + \delta) = (1-\alpha)Y_t / K_t. \tag{4}$$

The return on capital (net of depreciation), R_t, is subject to capital tax. The physical capital stock evolves according to

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{5}$$

where I_t is aggregate investment and δ is the depreciation rate.

The total factor productivity process λ_t is the only aggregate shock. The other state variables for the household are her productivity x_t, asset holdings a_t, and the distribution μ_t of productivities and asset holdings in the economy.

We specify the fiscal policy in this model such that transfers are constant over time. The government maintains a balanced budget in each period. It collects the revenue from income tax and spends it on fixed lump-sum transfers to households $\bar{T}$ or purchases of goods for its own consumption G_t.

$$\bar{T} + G_t = \tau_H W_t \int x_t h(a_t, x_t; \lambda_t, \mu_t)\, d\mu_t(a_t, x_t) + \tau_K R_t \int a_t d\mu_t(a_t, x_t). \tag{6}$$

In order to obtain total tax revenues we have to integrate over the distribution of household types using the measure $\mu_t(\cdot)$. For simplicity, we assume that government purchases G_t do not affect the household's marginal utility from private consumption or leisure nor the productivity of aggregate production function. For example, the utility from government purchases is additively separable from that of private consumption. Along with the assumption that the lump-sum transfer is constant, the government expenditure is not a time-varying aggregate state variable, which greatly simplifies the quantitative analysis.[3]

Since IOUs are in zero net supply, the overall net supply of assets has to equal the capital stock. Moreover, in equilibrium the labor hired by the firms has to equal the total supply of efficiency units by the households:

$$K_t = \int a_t d\mu_t(a_t, x_t), \quad L_t = \int x_t h(a_t, x_t; \lambda_t, \mu_t) d\mu_t(a_t, x_t). \tag{7}$$

Finally, the aggregate resource constraint can be expressed as

$$Y_t = \int c(a_t, x_t; \lambda_t, \mu_t) d\mu_t(a_t, x_t) + I_t + G_t. \tag{8}$$

It is useful to express the the households' optimization problem can be represented recursively as follows. Dropping time subscripts, suppose that the variable with $'$ denotes the value in the next period. the value function for an employed household, denoted by V^E, is given by

$$\begin{aligned} V^E(a, x; \lambda, \mu) = \max_{a' \in \mathcal{A}} \Bigg\{ & \frac{c^{1-\sigma} - 1}{1-\sigma} - B \frac{\bar{h}^{1+\gamma}}{1+\gamma} \\ & + \beta E\Big[\max\big\{ V^E(a', x'; \lambda', \mu'), V^N(a', x'; \lambda', \mu') \big\} \big| x, \lambda \Big] \Bigg\} \end{aligned} \tag{9}$$

subject to the constraints

$$c + a' = a + (1 - \tau_H) W x \bar{h} + (1 - \tau_K) R a, \quad a' \geq \underline{a},$$

$$\mu' = \mathbb{T}(\lambda, \mu),$$

where $\mathbb{T}(\cdot)$ denotes a transition operator that defines the law of motion for the distribution of household types $\mu(a, x)$. The value function for a non-employed household, denoted by $V^N(a, x; \lambda, \mu)$, is defined similarly with $h = 0$. Then, the labor-supply decision is characterized by:

$$V(a, x; \lambda, \mu) = \max_{h \in \{0, \bar{h}\}} \big\{ V^E(a, x; \lambda, \mu), V^N(a, x; \lambda, \mu) \big\}.$$

[3] In other words, with a stochastic movement in aggregate productivity, the total tax revenue will fluctuate over time in our model economy. Given the constant lump-sum transfer, the government spending, G_t,—which is irrelevant for the decision of households and firms—will adjust accordingly to balance the government budget constraint each period.

The households' decision rules for consumption $c(\cdot)$, asset holdings $a(\cdot)$, and labor supply $h(\cdot)$ are functions of the individual-specific state variables a and x and the aggregate states λ and μ.

To solve for the competitive equilibrium in the model economy, we use the "bounded rationality" method developed by Krusell and Smith (1998). We replace $\mu(a,x)$ by the finite set of moments—e.g., the mean of the asset—assuming that agents make use of a finite set of moments of μ in forecasting aggregate prices. We also assume that agents forecast the law of motion for these moments $\mathbb{T}$ using the log linear form. As in Krusell and Smith (1998), we achieve a fairly precise forecast when we use the first moment of μ only (i.e., aggregate capital, K). A detailed description of computational procedure can be found in Chang and Kim (2007).

2.2 Fiscal Policies

Fiscal policy in the model economy are characterized by labor and capital tax rates as well as the level of lump-sum transfers. We assume that the lump-sum transfer is a fixed fraction χ of steady state total tax revenues:

$$\bar{T} = \chi \left(\tau_H \bar{W} \int x h(a,x;\bar{\lambda},\bar{\mu})\ d\bar{\mu}(a,x) + \tau_K \bar{R} \int a\, d\bar{\mu}(a,x) \right), \tag{10}$$

where $\bar{\mu}$ denotes the steady state distribution of households.

Figure **??** depicts U.S. labor and capital tax rates, obtained from Chen, Imrohoroglu, and Imrohoroglu (2007). The capital tax rate has been falling from 45% to roughly 32% over the period from 1950 to 2003. Over the same time span the labor tax rate rose from about 22% to 30%. The ratio of transfer in total government expenditure $\chi = T/(T+G)$ rose from 22% to 42%. For our benchmark economy we choose the fiscal policy in year 1984, the midpoint of our sample ($\tau_H = 0.29$, $\tau_K = 0.35$, $\chi = 0.36$). With the caveat that in reality the government transfer payments are not made in a lump-sum fashion and distributed equally to all households.

In addition to our benchmark fiscal policy we consider 5 regimes of fiscal policy in Section 4: (i) low labor income tax ($\tau_H = 0.22$), (ii) high capital income tax ($\tau_K = 0.47$), (iii) higher ratio of lump-sum transfer in government expenditure ($\chi = 0.5$), (iv) the 1960 fiscal policy ($\tau_H = 0.229$, $\tau_K = 0.443$, $\chi = 0.224$) (v) the 2004 fiscal policy ($\tau_H = 0.269$,

$\tau_K = 0.327$, $\chi = 0.417$). These values, respectively, correspond to the lower or upper bound, or the beginning or end point of U.S. fiscal policy during the sample period.

2.3 Calibration

We briefly discuss the choice of the parameters of preferences and technology. A detailed discussion of the calibration approach can be found in Chang and Kim (2006, 2007). The unit of time is a quarter. Starting on the household side, we assume that the idiosyncratic productivity x_t follows an AR(1) process:

$$\ln x_t = \rho_x \ln x_{t-1} + \sigma_x \epsilon_{x,t}, \quad \epsilon_{x,t} \sim N(0,1). \tag{11}$$

The values of $\rho_x = 0.939$ and $\sigma_x = 0.287$ reflect the persistence and standard deviation of innovation to individual wages.[4] According to the Michigan Time-Use survey, a working individual spends one-third of his discretionary time $\bar{h} = 1/3$. We set the intertemporal substitution elasticity of hours worked equal to $\gamma = 0.4$. Given all other parameters, we set the preference parameter B such that the steady state employment rate is 60%, the average employment in our sample period. The discount factor β is chosen so that the quarterly rate of return to capital is 1% in the steady state. Finally, we let the borrowing constraint $\underline{a} = -2$, which roughly corresponds to two quarters of earnings in our calibration.

On the production side of the economy, we let capital depreciate at the rate $\delta = 0.025$ and set the capital share parameter $\alpha = 0.64$ to generate a labor share that is consistent with post-war U.S. data. The aggregate productivity shock, λ_t is a discrete approximation of a continuous AR(1) process:

$$\ln \lambda_t = \rho_\lambda \ln \lambda_{t-1} + \sigma_\lambda \epsilon_{\lambda,t}, \quad \epsilon_{\lambda,t} \sim \mathcal{N}(0,1). \tag{12}$$

We set $\rho_\lambda = 0.95$ and $\sigma_\lambda = 0.007$. These parameter values are obtained by fitting an AR(1) process to a Solow residual. Table 1 summarizes the parameter values of the benchmark economy. As mentioned earlier, the fiscal policy parameters in the benchmark economy are $\tau_H = 0.29$, $\tau_K = 0.35$, and $\chi = 0.36$.

[4] Chang and Kim (2007) restrict the household sample to those of household head ages between 35 and 55 with high school education to avoid the fixed effect in wages. With this restricted sample, the estimates are $\rho_x = 0.929$ and $\sigma_x = 0.227$. Here, however, we use the whole sample of PSID, ages 18 to 65 to encompass the overall distribution of wages and obtain a larger shocks for idiosyncratic productivity.

Since the goal of our analysis is to determine the magnitude of aggregation biases in policy predictions, it is desirable for the model economy to possess a realistic amount of heterogeneity and volatility of key aggregate variables, similar to that in U.S. data. Thus, we compare cross-sectional earnings and wealth – two important observable dimensions of heterogeneity in the labor market – found in the model and in the data. Figure **??** shows the Lorenz curves of family wealth and earnings distributions from both the Panel Study of Income Dynamics (PSID) and the model. Family wealth in the PSID (1984 survey) reflects the net worth of houses, other real estate, vehicles, farms and businesses owned, stocks, bonds, cash accounts, and other assets. Looking at the left panel of the figure, the wealth distribution is found to be more skewed in the data; the Gini coefficient of wealth distribution in the PSID is 0.76, whereas that in our model is 0.61. The right panel of the figure shows the Lorenz curves of earnings. Family earnings in the PSID are the sum of earnings of the household head and spouse. The earnings distribution appears more skewed in our model than in the data. This is because on average 40% of agents are not working in our model (recall that the steady state employment rate is 60%) whereas according to the 1984 PSID, only 18% of households reported zero earnings. In fact, as we calibrate the stochastic process of idiosyncratic productivity from the wage process, the Gini coefficients of earnings distribution of working households – those with non-zero labor income – in our model and PSID are almost identical.

Table 2 summarizes both the PSID (1984 survey) and the model's detailed information on wealth and earnings. Family wealth in the PSID reflects the net worth of houses, other real estate, vehicles, farms and businesses owned, stocks, bonds, cash accounts, and other assets. For each quintile group of wealth distribution, we calculate the wealth share, ratio of group average to economy-wide average, and the earnings share. In both the data and the model, the poorest 20 percent of families in terms of wealth distribution were found to own virtually nothing. The PSID found that households in the 2nd, 3rd, 4th, and 5th quintiles own 0.50, 5.06, 18.74, 76.22 percent of total wealth, respectively, while, according to the model, they own 3.27, 11.38, 24.74, 62.17 percent, respectively. The average wealth of those in the 2nd, 3rd, 4th, and 5th quintiles is, respectively, 0.03, 0.25, 0.93, and 3.81 times larger than that of a typical household, according to the PSID. These ratios are 0.16, 0.57, 1.24, and 3.11 according to our model. Households in the 2nd, 3rd, 4th, and 5th quintiles of the wealth distribution earn, respectively, 11.31, 18.72, 24.21, and 38.23 percent of total earnings, according to the PSID. The corresponding groups earn 15.76, 19.97, 23.72, and 30.81 percent, respectively, in the model. We deduce that the model economy presented in this paper possesses a reasonable degree of heterogeneity, thus making it possible to study the effects of aggregation in the labor market.[5]

We proceed by comparing business cycle statistics for aggregate output, consumption, and hours computed from data generated with the heterogeneous agent economy and post-war U.S. data. Data definitions for the U.S. time series are provided in the Appendix. Most importantly, we remove a linear deterministic trend from log output and consumption. Results are summarized Table 3. Actual output is slightly more volatile that aggregate output in the heterogeneous agent economy. A more striking difference is that the standard deviation of hours is three times more volatile in actual data than it is in the simulated data. This is in part due to low frequency labor supply shifts, not captured in the model economy. In fact, the volatility of hours in the model generated data is roughly in line with the volatility of actual Hodrick-Prescott filtered output, which removes the low frequency variation. Output, consumption, and hours are all positively correlated. The correlations between output and hours as well as consumption and hours are slightly stronger in the simulated data, than they are in U.S. data. Overall, the heterogeneous agent economy is successful in replicating salient business cycle features of U.S. macroeconomic time series.

3 A Representative Agent Model

In this section we describe a representative-agent DSGE model. We will estimate the taste and technology parameters of the DSGE model using the aggregate time series generated from the heterogeneous agent economy. In other words, we look for the parameters that best approximates the underlying heterogenous agent economy. We then use the estimated DSGE model to predict the effects of alternative fiscal policies and compare those with the actual equilibrium outcome from the heterogenous agent economies under those policies.

[5]The model economy, however, cannot generate an extreme concentration of wealth observed in the data. In the PSID, top 5% of households own 46% total wealth whereas in our model that group owns 25.5% of total wealth.

3.1 Model Specification

The model economy specified in Section 2 exhibits heterogeneity only in terms of the households. We replace the heterogeneous, borrowing constrained households by a stand-in representative household that solves the following problem:

$$\begin{aligned} \max \quad & \mathbb{E}_t\left[\sum_{s=0}^{\infty}\beta^{t+s}Z_{t+s}\left\{\ln C_{t+s}-\frac{(H_{t+s}/B_{t+s})^{1+1/\nu}}{1+1/\nu}\right\}\right] \\ \text{s.t.} \quad & C_t+K_{t+1}=K_t+(1-\tau_H)W_tH_t+(1-\tau_K)R_tK_t+\bar{T}. \end{aligned} \tag{13}$$

Because of incomplete capital markets and the indivisible nature of the labor supply, the households' preferences in the heterogeneous agent economy will not aggregate exactly to (13). As Scheinkman and Weiss (1986), Krüger and Lustig (2007), and Liu, Waggoner, and Zha (2008) show, capital market incompleteness can lead to a stochastic term in aggregate preferences. To capture this potential aggregation error we introduce the stochastic preference-shifters B_t and Z_t in (13), which are assumed to have an autoregressive law of motion:

$$\ln(B_t/\bar{B}) = \rho_B\ln(B_{t-1}/\bar{B})+\sigma_B\epsilon_{B,t}, \quad \epsilon_{B,t}\sim N(0,1) \tag{14}$$

$$\ln Z_t = \rho_Z\ln Z_{t-1}+\sigma_Z\epsilon_{Z,t}, \quad \epsilon_{Z,t}\sim N(0,1). \tag{15}$$

We also anticipate that the aggregate labor supply elasticity, denoted by ν, will be very different from the micro elasticity of household labor supply γ, that appears in (1). The representative household owns the capital stock and its budget constraint resembles that of the households at the micro-level. As in Section 2 the return R_t is defined in excess of the depreciation rate δ and the evolution of the capital stock is given by (5).

The production technology in the representative agent model is of the Cobb-Douglas form, identical to the one used in the heterogenous agent economy:

$$Y_t = A_tH_t^{\alpha}K_t^{1-\alpha}, \tag{16}$$

where technology evolves according to the AR(1) process

$$\ln(A_t/\bar{A}) = \rho_A\ln(A_{t-1}/\bar{A})+\sigma_A\epsilon_{A,t}, \quad \epsilon_{A,t}\sim N(0,1). \tag{17}$$

The first-order conditions for the firm's static profit maximization are identical to (4) except that L_t needs to be replaced by H_t. The produced output is either consumed by the representative household, invested to accumulate capital, or consumed by the government. Thus, the aggregate resource constraint takes the form

$$Y_t = C_t + I_t + G_t. \tag{18}$$

and resembles (8). Finally, as in the heterogeneous agent economy the government uses its tax revenues for transfers $\bar{T}$ and purchases G_t, maintaining a balanced budget:

$$\bar{T} + G_t = \tau_H W_t H_t + \tau_K R_t K_t. \tag{19}$$

To construct an approximate solution to the representative agent model, we log-linearize the equilibrium conditions around the deterministic steady state and apply a standard solution method for a linear rational expectations model.

3.2 Econometric Analysis

We will use Bayesian techniques developed in Schorfheide (2000) and surveyed in An and Schorfheide (2007) in Section 4 to estimate the representative agent model based on aggregated data from the heterogeneous agent economy. As observables we use log levels of consumption $C_t = \int c(a_t, x_t; \lambda_t, \mu_t) d\mu_t(a_t, x_t)$, employment rate $E_t = (1/\bar{h}) \int h(a_t, x_t; \lambda_t, \mu_t) d\mu_t(a_t, x_t)$, and output Y_t. Since α and δ are easily identifiable based on long-run averages of the labor share, and the investment-capital ratio, we fix these parameters in the estimation using the "true" values reported in Table 1. Moreover, we assume that the econometrician knows the "true" fiscal policy parameters.

Bayesian inference combines a prior distribution with a likelihood function to obtain a posterior distribution of the model parameters. Marginal prior distributions for the remaining parameters of the representative agent model are provided in Table 4. Our prior is diffuse with respect to the coefficients determining the law of motion of the exogenous shocks, and assigns a high probability to the event that the annualized real interest rate lies between 0 and 8% and the aggregate labor supply elasticity falls into the interval from 0 to 2. The joint prior distribution for all DSGE model parameters is obtained simply by taking the product of the marginals.

4 Quantitative Results

We consider three main questions in our quantitative analysis. First, we examine whether the aggregation manifests itself through sizeable preference shocks in the representative agent model. We do so by fitting the representative agent model to the data generated from the calibrated heterogeneous agent economy under the benchmark fiscal policy. We compare the estimates based on simulated data to those from U.S. economy. Second, we study to what extent the parameters of the representative agent model are invariant to changes in the fiscal policy. We do so by re-estimating the representative-agent DSGE model using the data generated from the heterogeneous agent model under different policy regimes. Finally, we use the benchmark DSGE model parameter estimates to predict the effect of policy changes assuming that taste and technology parameters are policy-invariant. We assess the accuracy of these predictions by comparing to the true steady states from the heterogeneous agent models.

4.1 Aggregation and Preference Shocks

We begin by estimating the DSGE model based on the aggregate time series generated from the heterogeneous agent economy under the benchmark fiscal policy. Posterior inference for the DSGE model parameters is conducted based on 200 observations. We also do the analysis based on 2500 observations (but with $\sqrt{T}$ adjusted to the small sample size of $\sqrt{200}$). Table 5 reports the estimates of a representative agent DSGE model that best approximates the aggregate time series of output, hour, consumption, and wage generated by the heterogeneous agent model. For comparison, we also report the estimates based on the actual U.S. aggregate data for 1960-2004. First, notice that the labor supply elasticity of a representative household (ν) is 1.72 quite different from $\gamma = 0.4$ that we assumed for the individual households in (1). This point has been stressed in Chang and Kim (2006). In a heterogeneous agent model (which features indivisible labor and incomplete markets), the aggregate elasticity is determined by the shape of reservation wage distribution, which we describe later, than the willingness of intertemporal substitution of leisure by individual households. More importantly for our exercise, although the technology shock is the only aggregate in the heterogeneous agent economy, the representative-agent DSGE model estimation detects both an intertemporal and an intratemporal preference shocks as in the data.

We plot the posterior estimates of the latent shock processes $\ln A_t$, $\ln B_t$, and $\ln Z_t$ in Figure **??**. For the technology shock, we overlay the "true" series of aggregate productivity ($\ln \lambda_t$) with the Kalman smoother-based estimate of productivity ($\ln A_t$). While the two series are highly correlated, they are not identical. In particular, the measured TFP ($\ln A_t$) appears to be less volatile than the true technology shock ($\ln \lambda_t$). This is because of the composition effect (e.g., Bils (1985)). During the expansion, the demand for labor increases thanks to a higher aggregate productivity. In the heterogeneous agent economy, newly hired workers are, on average, less productive than existing workers, lowering the average productivity of the workforce. Vice versa, in recessions it is the low productivity workers who leave the labor market. This compositional effect of the workforce makes the measured aggregate productivity less volatile than the true aggregate technology. It also contributes to a larger estimate of aggregate labor supply because the measured hours exhibits a larger volatility than the hours in efficiency units.

The preference shocks themselves are difficult to interpret. While we estimated the representative agent model subject to the assumption that all three shock processes are uncorrelated at all leads and lags, it turns out that *ex post* the correlation between the technology process and the intratemporal (intertemporal) preference shocks is 0.30 (0.2). A variance decomposition of the observables, based on the *a priori* assumption of uncorrelated shocks, is provided in Table 6. Jointly, the two preference shocks account for about 10% of the variation in output and consumption, and more than 50% percent of the variation in hours worked.

To put these numbers into perspective, we also estimated the representative agent model to U.S. data from 1964 to 2006. The variance decomposition based on actual data assigns even more importance to the intratemporal preference shock, as it explains almost 50% of the fluctuations in output and consumption and almost all the variation in employment. To the extent that U.S. business cycles are driven by other demand shocks, it is probably not surprising that the preference shock plays a larger role in the actual data. Moreover, as shown in Table 5, the estimated aggregate labor supply elasticity ($\hat{\nu} = 0.34$) based on U.S. data is much smaller, than the labor supply estimate ($\hat{\nu} = 1.72$) obtained from the simulated data.[6] A low aggregate labor supply elasticity implies that technology shocks only have a small effect on the fluctuations of hours worked, which means that non-technology shocks need to generate almost all of the hours variation. While it is difficult to make direct comparisons with the literature that estimates richer DSGE models or employs alternative empirical methods, a substantial variance share of intratemporal preference shocks for employment or hours worked seems broadly in line with recent studies by Hall (1997) and Chari, Kehoe, McGrattan (2007), and Justinano, Primiceri, and Tambalotti (2009). The overall role of the intertemporal shock Z_t in the model estimated based on simulated data, also appears to be smaller than those based on U.S. data (or those in the literature). Z_t captures different types of misspecifications of the consumption Euler equation. The fact that our estimation excludes the use of asset returns might explain the muted role of this shock.

Before we proceed to the policy changes, we shall comment on the model fit. It is conceivable that the preferences in the representative agent model are poorly chosen. We therefore compute posterior odds of the estimated DSGE model relative to a VAR(4) with Minnesota prior. For actual U.S. data these odds are e^{46} in favor of the VAR, indicating some model misspecification. If we replace the U.S. time series by the data generated with our representative agent model, then the posterior odds favor the DSGE model by e^{23}. This calculation indicates, that the estimated representative agent model fits the data from the heterogeneous agent economy well, compared to the fit that is attainable with actual data.

4.2 Policy (In)variance of DSGE Model Parameters

We repeat the estimation of a representative agent DSGE model using the simulated aggregate data from the heterogeneous agent model under different fiscal policy regimes. If the representative agent parameters were truly "structural" the parameter estimates should be the same (up to some estimation uncertainty), regardless of the policy regime.

In Table 7 we reports the steady state values from the heterogeneous agent model under various fiscal policies. For example, when the labor income tax rate is lowered ($\tau_H = 0.22$), employment rate increases by almost 7% (from 60% to 63.8%). Because of low tax rate, the total tax revenue decreases (not reported). Given the fixed proportion of lump-sum transfer

[6] A more detailed empirical analysis based on post-war U.S. data can be found in Rios-Rull, Schorfheide, Fuentes-Albero, Kryshko, and Santaeulalia-Llopis (2009).

($\chi = 0.36$), each household receive less amount of lump-sum transfer and saves more for precautionary savings. As a result, the aggregate capital stock increases by 6% (from 15.17 to 16.07), lowering an equilibrium annual interest rate from 4% to 3.68%. Aggregate output increases about 4%, smaller than the employment increase of 7%. This is mostly due to the compositional effect. In our heterogeneous agent model, workers with high-productivity (or low assets) are likely to participate the labor market. Thus, an increased employment in a new steady state have to draw from less-productive workers. As a result, the average productivity decreases significantly from 2.46 to 2.39.

When we increase the capital income tax rate (to $\tau_K = 0.47$), the equilibrium employment rate is little affected. A high capital tax, however, discourages savings and results in a much lower capital stock (from 15.2 to 14), raising the equilibrium interest rate from 4% to 4.76%. When we increase the ratio of lump-sum transfer ($\chi = 0.5$) in government expenditure, it creates a negative effect on labor supply through income effect, decreasing the employment rate to 57%. A larger transfer also discourages the precautionary motive of savings, decreasing aggregate capital stock to from 15.2 to 14.76. The labor productivity, however, increases as the employment rate decrease— a relatively less-productive workers retreat from the labor market. When we shift the fiscal policy parameters to the values in 1960 ($\tau_H = 0.229$, $\tau_K = 0.443$, $\chi = 0.224$), employment rate increases to 66%. A low labor income tax provides more incentive to work (substitution effect) and the the reduction of the lump-sum transfers generates an income effect for the households, especially those near the borrowing constraint, making them work in the labor market. This also creates a motive for precautionary savings, rasing the aggregate capital stock slightly. A big push in employment rate leads to a significant decrease in average labor productivity, almost 9% drop.

We repeat the estimation of the DSGE model using the time series data generated by heterogenous agent model under different fiscal policies. Looking at Table 5, we notice that the estimates of the aggregate labor supply elasticity ν, the level of productivity $\ln \bar{A}$, and the persistence of the intratemporal preference shock ρ_B are markedly different in the sense that there is no overlap of the 90% Bayesian credible intervals. A higher employment rate moves the economy toward a thinner part of reservation wage distribution, the aggregate elasticity of labor supply, ν, becomes smaller. At the same time, as the economy hires less-skilled workers, the average productivity of workforce deteriorates, leading to a low estimate of $\ln \bar{A}$.

To illustrate the impact of these fiscal policy changes on the aggregate elasticity of labor supply, we draw pseudo aggregate labor supply schedules based on the steady-state reservation wage distributions (i.e., the inverse function of the cumulative reservation wage distribution) in Figure **??**. Each curve represents the employment rate (on the x-axis) at a given wage rate (y-axis). The vertical line denotes the steady state level of employment under each policy regime. In all cases, the aggregate labor supply schedule becomes steeper toward the full employment level, as the economy moves toward the right tail of the reservation wage distribution. This implies that the aggregate labor supply will exhibit different elasticities for different levels of employment as well as different policy regimes. For example, in the benchmark economy, the steady state employment rate is 60% and the elasticity at that point is 1.2. With a low labor income tax rate, the steady state employment rate increases to 62% and the elasticity around that point is 1.13. Under the 1960 policy (characterized by a low labor income tax rate, a higher capital income tax, and smaller lump-sum transfer), the steady state employment rate increases to 62% and the elasticity around that point is 0.89.

According to the DSGE model estimates in Table 5, the labor supply elasticity is 1.72 in the benchmark and 1.07 under the 1960 fiscal policy. While the estimated aggregate labor supply elasticities are not exactly equal to the elasticities calculated from the slope of the reservation wage distribution in the underlying heterogeneous agent economy, the pattern is very similar.[7] The aggregate labor supply elasticities are important for the propagation of technology shocks. Suppose the fiscal policy has changed to the values of 1960. If one assumes incorrectly that ν is 1.72 instead of 1.07, then he would predict that a one-percent temporary increase in aggregate productivity would raise the aggregate employment by about 1.72% instead of 1.07%. In Table 8, we find a similar pattern across policies. When the fiscal policy changes, the estimated elasticity of aggregate labor supply varies; the average productivity falls whenever total employment increases (due to compositional effect); the estimated persistence of preference shocks varies.[8]

[7] In fact, the DSGE estimate of labor supply should not be the same as the one computed from the slope of reservation wage distribution of the heterogeneous agent economy. The elasticity based on the slope of the reservation wage distribution assume that the entire wealth-earnings distribution remains unchanged whereas the aggregate productivity shock shifts the wealth-earnings distribution over time.

[8] when we use the effective units of labor in the estimation of the representative-agent DSGE model in

4.3 Accuracy of DSGE Model-Based Policy Predictions

We now use the estimated benchmark model to predict the effect of fiscal policy changes on long-run averages of hours worked, consumption, and output. In addition to our benchmark fiscal policy we consider 5 regimes of fiscal policy: (i) low labor income tax ($\tau_H = 0.22$), (ii) high capital income tax ($\tau_K = 0.47$), (iii) higher ratio of lump-sum transfer in government expenditure ($\chi = 0.5$), (iv) the 1960 fiscal policy ($\tau_H = 0.229$, $\tau_K = 0.443$, $\chi = 0.224$) (v) the 2004 fiscal policy ($\tau_H = 0.269$, $\tau_K = 0.327$, $\chi = 0.417$). These values, respectively, correspond to the upper bound, the lower bound, the beginning, or end point of the sample period.

The results are summarized in Table 9. The entries in the table refers to the percentage change relative to the benchmark values. The "true" policy effect is computed from the heterogeneous agent economy. The "90 % interval" corresponds to the 90% based on the posterior estimates of the representative agent DSGE model, estimated based on the benchmark economy. Our goal is to predict the percentage change in average hours, consumption, and output, assuming that the representative agent's preferences and technology are invariant to a change in the fiscal policy. These intervals reflect the uncertainty with respect to the "structural" parameters of the representative agent model. Based on the previous analysis, we would expect that the DSGE model predictions suffer from aggregation bias. However, it is a priori unclear how large these aggregation biases are compared to the overall level of uncertainty associated with our predictions.

For example, looking at the fourth row of the Table, moving to the 1960 fiscal policy lowers the labor income tax from 29% to 23%, raises capital tax to 44% and decreases the transfer rate 22%. This increases total hours worked by 9.95 percent according to the "true " heterogeneous agent economy. However, according to the representative agent model, whose preferences and technology estimated from the benchmark are invariant to the policy changes, hours are predicted to increase between 5.18% and 5.51% (with 90% of confidence). There are two reasons why the representative agent DSGE model underpredict the "true" effect from the heterogeneous agent model. For one, hours measured in physical units tends to move more than the hours measured in efficiency unit. For two, in a heterogenous agent model, a low rate of lump-sum transfer creates strong income effects

Appendix Table **??**, the estimates of ν, $\bar{A}$ and rho_B remain quite stable, highlighting the importance of cross-sectional heterogeneity in productivity across households.

for poor households near the borrowing constraint, making them participating the labor market despite a low productivity. Across the entries in the table, we often find that the "true" effect lies outside the 90% intervals. Thus, using Geweke's terminology, the lack of invariance of the aggregator function is sufficiently strong to render predictions from the representative agent model inaccurate.

4.4 Welfare Costs of Policy Changes

The welfare is of great concern for any government policy. We examine whether potential bias in the predictions based on the representative-agent DSGE model has a quantitatively important consequence in the welfare cost as well. We adopt the consumption-based measure which is standard in the literature in comparing the social welfare associated with a policy change in heterogeneous agents models. Following Aiyagari and McGrattan (1998), we define the social welfare as:[9]

$$\mathcal{W} = \int V(a,x) d\mu(a,x), \tag{20}$$

where $\mu(a,x)$ is the steady state joint distribution of asset holdings and idiosyncratic produtivity and $V(a,x)$ is the value function associated with the optimal decisions, i.e.,

$$V(a,x) = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log c(a_t, x_t) - B \frac{h(a_t, x_t)^{1+1/\gamma}}{1+1/\gamma} \right\} d\mu(a_t, x_t), \tag{21}$$

where $c(a,x)$ and $h(a,x)$ are the optimal decision rules for an individual whose asset holdings are a and idiosyncratic productivity is x. This welfare measure can be thought of as a utilitarian social welfare function and also as steady state ex ante welfare, i.e., welfare of a typical consumer before he realizes his initial assets and the productivity shock, which are assumed to be drawn from the steady state distribution $\mu(a,x)$.

We will measure the welfare gain or loss due to a policy change by the constant percentage change in consumption each period for all individuals that is required to equate the

[9]This measure of social welfare or its variants have been widely used in the literature. Examples include Domeij and Heathcote (2004), Young (2004), Pijoan-Mas (2005), Heathcote, Storesletten and Violante (2008) and Rogerson (2009). Detailed justifications for this welfare measure are provided in Aiyagari and McGrattan (1998).

social welfares between before and after the policy change. Specifically, we will compute Δ that solves

$$\int \left\{ \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left\{ \log\big((1+\Delta)c_0(a_t,x_t)\big) - B\frac{h_0(a_t,x_t)^{1+1/\gamma}}{1+1/\gamma} \right\} \right] \right\} d\mu_0(a_t,x_t)$$
$$= \int \left\{ \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left\{ \log c_1(a_t,x_t) - B\frac{h_1(a_t,x_t)^{1+1/\gamma}}{1+1/\gamma} \right\} \right] \right\} d\mu_1(a_t,x_t) \tag{22}$$

where, c_0, h_0 and μ_0 are the decision rules for consumption and labor supply and the steady state distribution in the benchmark economy while c_1, h_1 and μ_1 are those associated with the policy change. A positive Δ implies that the policy change is welfare improving.

Applying the definitions of out social welfare and the optimal value function, equation (22) simplifies as follows:

$$\mathcal{W}_1 = \mathcal{W}_0 + \frac{1}{1-\beta}\log(1+\Delta), \tag{23}$$

where $\mathcal{W}_0$ and $\mathcal{W}_1$ are the social welfares before and after the policy change, respectively. Hence,

$$\Delta = \exp\big((\mathcal{W}_1 - \mathcal{W}_0)(1-\beta)\big) - 1 \tag{24}$$

We use the same measure for the representative agent models, where computation is much simpler because the distribution $\mu(a,x)$ is degenerate. The measure of welfare cost (or gain) Δ solves

$$\log(1+\Delta) = \log\big(\bar{C}_1/\bar{C}_0\big) - B\frac{\bar{H}_1^{1+1/\gamma} - \bar{H}_0^{1+1/\gamma}}{1+1/\gamma}, \tag{25}$$

where $\bar{C}_0$ and $\bar{H}_0$ are the steady state values of consumption and labor supply in the benchmark economy while $\bar{C}_1$ and $\bar{H}_1$ are those in an economy with different policy.

Table **??** show the welfare gain (or cost) associated with new fiscal policies. [**Need numbers from DSGE models**].

5 Conclusion

A key assumption underlying the policy analysis with representative agent DSGE models is that taste and technology parameters as well as structural shocks are policy invariant. We generate aggregate time serious data from a calibrated heterogeneous agent economy in which aggregation is imperfect because individual households face idiosyncratic productivity shocks, borrowing constraints, and incomplete asset markets. We then estimate the taste and technology parameters of a representative-agent DSGE model that best approximates the aggregate behavior of the underlying heterogenous agent economy. We find that imperfect aggregation of an heterogeneous agent economy is captured by the preference shock in the representative agent model. Neither the aggregate labor supply elasticity nor the preference shock processes are invariant to changes in tax rates and the composition of government spending. The aggregation biases in the prediction of policy effects tend to be larger than the predictive intervals that reflect estimation uncertainty for the representative agent's taste or technology.

References

Aiyagari, S. Rao (1994): "Uninsured Idiosyncratic Risk and Aggregate Saving," *Quarterly Journal of Economics*, **109(3)**, 659-684.

Aiyagari, S. Rao, and Ellen R. McGrattan (1998): "The Optimum Quantity of Debt," *Journal of Monetary Economics*, Vol. 42, pp. 447–469.

An, Sungbae, Yongsung Chang, and Sun-Bin Kim (2009): "Can a Representative Agent Model Represent a Heterogeneous Agent Economy?" *American Economic Journal - Macroeconomics*, **1(2)**, 29-54.

An, Sungbae, and Frank Schorfheide (2007): "Bayesian Analysis of DSGE Models," *Econometric Reviews*, **26(2-4)**, 113-172.

Bewley, Truman F. (1983): "A Difficulty with the Optimum Quantity of Money," *Econometrica*, **51**, 1485-1504.

Bils, Mark. (1985): "Real Wages over the Business Cycle: Evidence from Panel Data." *Journal of Political Economy*, 93(4), 666–689.

Chang, Yongsung, and Sun-Bin Kim (2006): "From Individual to Aggregate Labor Supply: A Quantitative Analysis Based on a Heterogeneous Agent Macroeconomy," *International Economic Review*, **47(1)**, 1-27.

Chang, Yongsung, and Sun-Bin Kim (2007): "Heterogeneity and Aggregation: Implications for Labor-Market Fluctuations," *American Economic Review*, **97(5)**, 1939-1956.

Chari, V.V., Patrick Kehoe, and Ellen McGrattan (2007): "Business Cycle Accounting," *Econometrica*, **75(3)**, 781-836.

Chen, Kaiji, Ayse Imrohoroglu, and Selahattin Imrohoroglu (2007): "A Quantitative Assessment of the Decline in the U.S. Saving Rate," *Manuscript*, University of Southern California.

Christiano, Lawrence, Martin Eichenbaum, and Charles Evans (2005): "Nominal Rigidities and the Dynamic Effect of a Shock to Monetary Policy," *Journal of Political Economy*, **113**, 1-45.

Domeij, David, and Jonathan Heathcote (2004): "On the Distributional Effects of Reducing Capital Taxes," *International Economic Review*, Vol. 45, No. 2, pp. 523–554.

Fernández-Villaverde, Jesús, and Juan F. Rubio-Ramiréz (2008): "How Structural Are Structural Parameters?," *2007 NBER Macroeconomics Annual*, MIT Press, 83-138.

Galí, Jordi, Mark Gertler, and J. David Lopéz-Salido (2007): "Markups, Gaps, and the Welfare Costs of Business Fluctuations," *Review of Economics and Statistics*, **89(1)**, 44-59.

Geweke, John (1985): "Macroeconomic Modelling and the Theory of the Representative Agent," *American Economic Review: Papers and Proceedings*, **75(2)**, 206-210.

Huggett, Mark (1993): "The Risk-Free Rate in Heterogeneous-Agent Incomplete-Insurance Economies," *Journal of Economic Dynamics and Control*, **17(5-6)**, 953-969.

Hall, Robert E. (1997): "Macroeconomic Fluctuations and the Allocation of Time," *Journal of Labor Economics*, **15**, S223-S250.

Heathcote, Jonathan, Kjetil Storesletten, and Giovanni L. Violante (2008): "Insurance and Opportunities: A Welfare Analysis of Labor Market Risk," *Journal of Monetary Economics*, Vol. 55, pp. 501–525.

Justinano, Alejandro, Giorgio Primiceri, and Andrea Tambalotti (2009): "Investment Shocks and Business Cycles," *Manuscript*, Northwestern University.

King, Robert G., Charles I. Plosser, and Sergio T. Rebelo (1988): "Production, Growth and Business Cycles: I. The Basic Neoclssical Model," *Journal of Monetary Economics*, **21(2-3)**, 195-232.

Krüger, Dirk, and Hanno Lustig (2007): "When is Market Incompleteness Irrelevant for the Price of Aggregate Risk?" *Manuscript*, University of Pennsylvania.

Krusell, Per, Toshihiko Mukoyama, Richard Rogerson, Aysegul Sahin (2008): "The Aggregate Implications of Indivisible Labor, Incomplete Markets and Search Frictions," *Journal of Monetary Economics*, **55(5)**, 961-979.

Krusell, Per, and Anthony A. Smith, Jr. (1998): "Income and Wealth Heterogeneity in the Macroeconomy," *Journal of Political Economy*, **106(5)**, 867-896.

Kydland, Finn E., and Edward C. Prescott (1982): "Time to Build and Aggregate Fluctuations," *Econometrica*, **50(6)**, 1345-1370.

Ljungqvist, Lars, and Thomas Sargent (2007): "Indivisible Labor, Human Capital, Lotteries, and Personal Savings: Do Taxes Explain European Employment?" *2006 NBER Macroeconomics Annual*, MIT Press, 181-224.

Lucas, Robert E. Jr. (1976): "Econometric Policy Evaluation: A Critique," *Carnegie-Rochester Conference on Public Policy*, **1**, 19-46.

Lucas, Robert E., Jr., and Leonard A. Rapping (1969): "Real Wages, Employment, and Inflation," *Journal of Political Economy*, **77(5)**, 721-754.

Liu, Zheng, Daniel Waggoner, and Tao Zha (2008): "Asymmetric Expectation Effects of Regime Switches in Monetary Policy," *Manuscript*, Federal Reserve Bank of Atlanta.

MaCurdy, Thomas E. (1981): "An Empirical Model of Labor Supply in a Life-Cycle Setting," *Journal of Political Economy*, **89(6)**, 1059-1085.

Mulligan, Casey (2001): "Aggregate Implications of Indivisible Labor," *Advances in Macroeconomics*, **1(1)**, Article 4.

Mankiw, N. Gregory, Julio J. Rotemberg, and Lawrence H. Summers (1985): "Intertemporal Substitution in Macroeconomics," *Quarterly Journal of Economics*, **100(1)**, 225-251.

Nakajima, Makoto (2007) "Business Cycles in the Equilibrium Model of Labor Search and Self-Insurance," *Manuscript*, Federal Reserve Bank of Philadelphia.

Pijoan-Mas, Josep (2005): "Precautionary Savings or Working Longer Hours?" *Review of Economic Dynamics*, Vol. 9, pp. 326–352.

Rios-Rull, Jose-Victor, Frank Schorfheide, Cristina Fuentes-Albero, Maxym Kryshko, and Raul Santaeulalia-Llopis (2009): "Methods versus Substance: Measuring the Effects of Technology Shocks," *NBER Working Paper*, **15375**.

Rogerson, Richard (1988): "Indivisible Labor, Lotteries and Equilibrium," *Journal of Monetary Economics*, **21(1)**, 3-16.

Rogerson, Richard (2009): "Taxes, Transfers and Employment in an Incomplete Markets Model," manuscript.

Rogerson, Richard, and Johanna Wallenius (2009): "Micro and Macro Elasticities in a Life Cycle Model with Taxes," *Journal of Economic Theory*, forthcoming.

Schorfheide, Frank (2000): "Loss Function Based Evaluation of DSGE Models," *Journal of Applied Econometrics*, **15(6)**, 645-670.

Scheinkman, Jose A., and Laurence Weiss (1986): "Borrowing Constraints and Aggregate Economic Activity," *Econometrica*, **54**, 23-45.

Smets, Frank, and Rafael Wouters (2003): "An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association*, **1**, 1123-1175.

Young, Eric R. (2004), "Unemployment Insurance and Capital Accumulation," *Journal of Monetary Economics*, Vol. 51, pp. 1683–1710.

Table 1: PARAMETERS OF THE HETEROGENEOUS AGENT ECONOMY

Parameter	Description
$\beta = 0.98332$	Discount factor
$\gamma = 0.4$	Intertemporal substitution elasticity of leisure
$B = 101$	Utility parameter
$\overline{h} = 1/3$	Labor supply if working
$\underline{a} = -2.0$	Borrowing constraint
$\rho_x = 0.939$	Persistence of idiosyncratic productivity shock
$\sigma_x = 0.287$	Standard deviation of innovation to idiosyncratic productivity
$\alpha = 0.64$	Labor share in production function
$\delta = 0.025$	Capital depreciation rate
$\rho_\lambda = 0.95$	Persistence of aggregate productivity shock
$\sigma_\lambda = 0.007$	Standard deviation of innovation to aggregate productivity

Table 2: Characteristics of Wealth Distribution

	Quintile					
	1st	2nd	3rd	4th	5th	Total
PSID						
Share of wealth	-.52	.50	5.06	18.74	76.22	100
Group average/population average	-.02	.03	.25	.93	3.81	1
Share of earnings	7.51	11.31	18.72	24.21	38.23	100
Benchmark Model						
Share of wealth	-1.56	3.27	11.38	24.74	62.17	100
Group average/population average	-.08	.16	.57	1.24	3.11	1
Share of earnings	9.74	15.76	19.97	23.72	30.81	100

Notes: The PSID statistics reflect the family wealth and earnings levels published in their 1984 survey. Family wealth in the PSID reflects the net worth of houses, other real estate, vehicles, farms and businesses owned, stocks, bonds, cash accounts, and other assets.

Table 3: Second Moments of Simulated and U.S. Data

	Model 3000 obs.	U.S. Data 1964-2006
$\sigma(\ln Y)$	.033	.041
$\sigma(\ln C)$	.020	.021
$\sigma(\ln H)$	.013	.042
$\sigma((\ln H)_{HP})$	.007	.018
$\mathrm{corr}(\ln Y, \ln C)$	0.84	0.83
$\mathrm{corr}(\ln Y, \ln H)$	0.80	0.56
$\mathrm{corr}(\ln C, \ln H)$	0.37	0.51

Notes: $\sigma(\cdot)$ is sample standard deviation, $\mathrm{corr}(\cdot)$ is sample correlation, and $(\ln H)_{HP}$ denotes HP filtered (smoothing parameter 1,600) log hours. Unless noted otherwise, we extract a linear trend from the U.S. data before computing the sample moments.

Table 4: Prior Distributions for DSGE Model Estimation

Name	Domain	Density	Mean	S.D.
ν	$\mathbb{R}^+$	Gamma	1.00	0.50
$\ln \bar{A}$	$\mathbb{R}$	Normal	0.00	10.0
$\ln \bar{B}$	$\mathbb{R}$	Normal	0.00	10.0
ρ_A	$[0, 1)$	Beta	0.50	0.25
ρ_B	$[0, 1)$	Beta	0.50	0.25
σ_A	$\mathbb{R}^+$	Inv. Gamma	.012	.007
σ_B	$\mathbb{R}^+$	Inv. Gamma	.012	.007
σ_Z	$\mathbb{R}^+$	Inv. Gamma	.012	.007
R	$\mathbb{R}^+$	Gamma	4.00	2.00

Notes: The means and standard deviations of priors. The following parameters are fixed: $\alpha = 0.64$, $\delta = 0.025$, $\rho_Z = 0.99$. Moreover, we fix the policy parameters τ_H, τ_K, and χ at their "true" values. R is annualized discount rate $R = 400 \times (1/\beta - 1)$.

Table 5: Parameter Estimates

	Benchmark		1960s Taxes		U.S. Data	
	Mean	90% Intv.	Mean	90% Intv	Mean	90% Intv
Sample Size $T = 200$						
ν	1.72	[1.57, 1.86]	1.07	[0.88, 1.28]	0.34	[0.10, 0.60]
$\ln \bar{A}$	-0.26	[-0.26, -0.26]	-0.30	[-0.31, -0.29]	-0.25	[-0.27, -0.22]
$\ln \bar{B}$	-0.33	[-0.34, -0.32]	-0.32	[-0.33, -0.31]	-0.44	[-0.52, -0.37]
R	2.83	[2.68, 2.98]	2.61	[2.43, 2.80]	3.70	[3.25, 4.22]
ρ_A	0.90	[0.89, 0.91]	0.95	[0.94, 0.95]	0.97	[0.96, 0.99]
ρ_B	0.76	[0.60, 0.92]	0.91	[0.89, 0.93]	0.98	[0.97, 1.00]
σ_A	.005	[.005, .006]	.006	[.006, .007]	.006	[.006, .007]
σ_B	.003	[.002, .003]	.003	[.002, .003]	.007	[.007, .008]
σ_Z	.003	[.002, .003]	.002	[.002, .002]	.012	[.010, .013]
Sample Size $T = 2,500$						
ν	2.14	[2.01, 2.26]	1.22	[1.17, 1.26]		
$\ln \bar{A}$	-0.26	[-0.26, -0.26]	-0.30	[-0.30, -0.30]		
$\ln \bar{B}$	-0.32	[-0.32, -0.31]	-0.31	[-0.31, -0.31]		
R	2.77	[2.71, 2.83]	2.53	[2.46, 2.58]		
ρ_A	0.91	[0.91, 0.92]	0.94	[0.94, 0.94]		
ρ_B	0.92	[0.92, 0.93]	0.93	[0.93, 0.93]		
σ_A	.005	[.005, .006]	.006	[.006, .006]		
σ_B	.003	[.003, .003]	.002	[.002, .002]		
σ_Z	.003	[.003, .003]	.002	[.002, .002]		

Notes: The following parameters are fixed during the estimation τ_H, τ_K, χ as tabulated, $\delta = 0.025$, $\rho_Z = 0.99$. The estimates of R reflects the annualized discount rate $R = 400 \times (1/\beta - 1)$.

Table 6: Relative Importance of Preference Shocks

	B		Z	
	Mean	90% Intv.	Mean	90% Intv.
Benchmark Economy, $T = 200$				
Output	5	[2, 8]	5	[4, 6]
Consumption	3	[0, 7]	6	[4, 7]
Hours	33	[18, 45]	5	[3, 7]
Benchmark Economy, $T = 2,500$				
Output	9	[8, 10]	5	[4, 5]
Consumption	9	[8, 10]	4	[4, 5]
Hours	43	[41, 46]	4	[4, 4]
U.S. Data				
Output	45	[21, 68]	5	[2, 9]
Consumption	47	[21, 75]	6	[1, 10]
Hours	98	[97, 99]	1	[0, 1]

Notes: The entries correspond to percentages.

Table 7: Steady States of Heterogeneous Agent Model under Different Policies

	Bench-mark	Lab. Tax Cut	Cap. Tax Raise	More Transfers	1960 Policy	2004 Policy
τ_H	0.29	0.22			.229	.269
τ_K	0.35		0.47		.443	.327
χ	0.36			0.50	.224	.417
Employment E	0.600	0.638	0.599	0.569	0.660	0.599
Capital K	15.17	16.07	14.00	14.76	15.37	15.53
Output Y	1.475	1.527	1.434	1.444	1.514	1.488
Labor Productivity Y/E	2.458	2.393	2.394	2.538	2.294	2.484
Interest Rate R (Annual)	4.00	3.68	4.76	4.04	4.16	3.80

Table 8: POSTERIOR MEAN PARAMETER ESTIMATES, $T = 200$

	Bench-mark	Lab. Tax Cut	Cap. Tax Raise	More Transfers	1960 Policy	2004 Policy
τ_H	0.29	0.22			.229	.269
τ_K	0.35		0.47		.443	.327
χ	0.36			0.50	.224	.417
ν	1.72	1.12	1.67	2.68	1.07	1.70
$\ln \bar{A}$	-0.26	-0.29	-0.26	-0.24	-0.30	-0.26
$\ln \bar{B}$	-0.33	-0.33	-0.33	-0.32	-0.32	-0.33
ρ_A	0.90	0.94	0.92	0.92	0.95	0.94
ρ_B	0.76	0.90	0.87	0.90	0.91	0.92
σ_A	.005	.006	.006	.005	.006	.006
σ_B	.003	.003	.003	.003	.003	.003
σ_Z	.003	.003	.003	.002	.002	.003
R	2.83	2.64	2.84	2.96	2.61	2.80

Notes: The following parameters are fixed during the estimation τ_H, τ_K, χ as tabulated, $\delta = 0.025$, $\rho_Z = 0.99$. R reflects the annualized discount rate $R = 400 \times (1/\beta - 1)$.

Table 9: PREDICTIONS OF STEADY STATE CHANGES, $T = 200$

		Hours	Consumption	Output
Labor Tax Cut	"True"	6.30	7.61	3.50
$\tau_H = 0.22$	90 % Intv.	[2.96, 3.15]	[7.84, 8.03]	[2.96, 3.15]
Capital Tax Raise	"True"	-0.15	-2.69	-2.85
$\tau_K = 0.47$	90 % Intv.	[-0.31, -0.28]	[-3.63, -3.37]	[-4.07, -3.84]
More Transfers	"True"	-5.25	3.09	-2.17
$\chi = 0.5$	90 % Intv.	[-3.22, -3.04]	[1.79, 1.98]	[-3.22, -3.04]
1960 Fiscal Policy	"True"	9.95	1.75	2.60
$\tau_H = 0.229$, $\tau_K = 0.443$, $\chi = 0.224$	90 % Intv.	[5.18, 5.51]	[2.25, 2.65]	[2.28, 2.63]
2004 Fiscal Policy	"True"	-0.15	3.93	0.82
$\tau_H = 0.269$, $\tau_K = 0.327$, $\chi = 0.417$	90 % Intv.	[-0.21, -0.20]	[3.66, 3.71]	[0.36, 0.41]

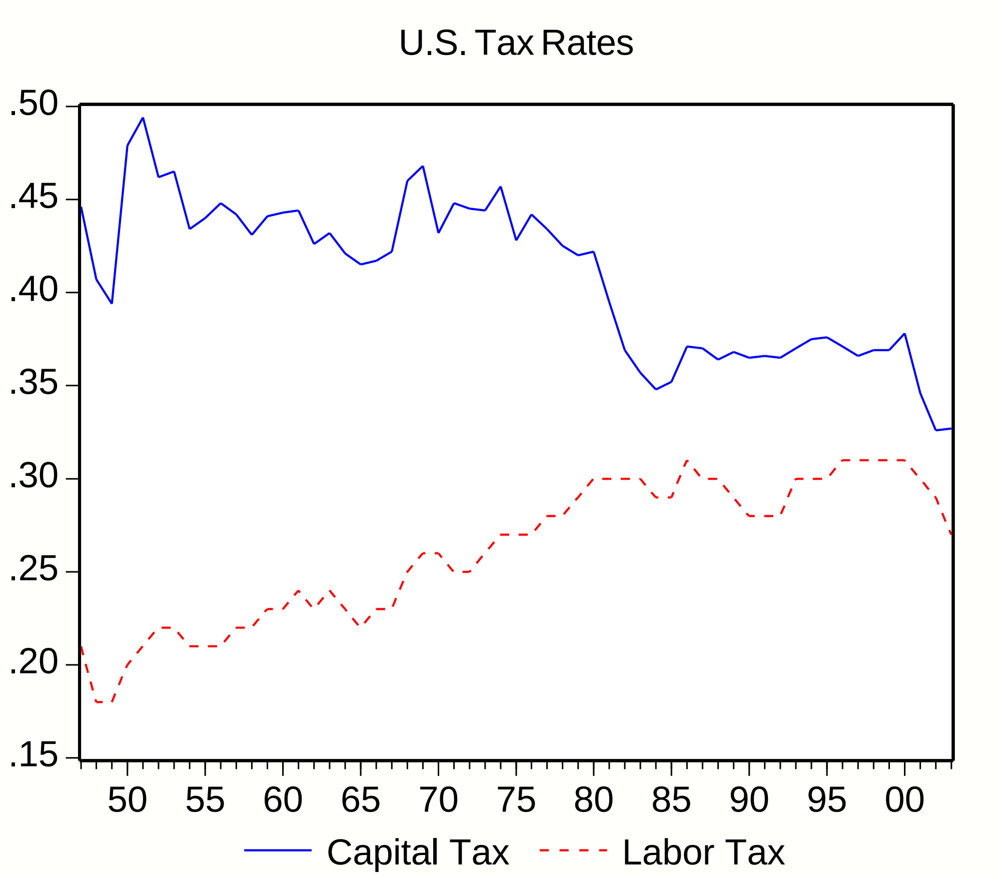
Notes: The benchmark policy is $\tau_H = 0.29$, $\tau_K = 0.35$, $\chi = 0.36$. The entries in the table refer to percentage changes relative to the benchmark policy. "True" effects are computed from the means of the ergodic distributions of the heterogeneous agent economy. 90% Intv. are predictive intervals computed from the posterior of the representative agent model based on observations under the benchmark policy.

Table 10: Welfare Gain or Lost Associated with Various Policies

Policy	"True"	Mean	90 % Interval
Low labor income tax rate: $\tau_H = 0.22$	0.0451	0.0664	[0.0660, 0.0668]
High capital income tax rate: $\tau_k = 0.47$	-0.0261	-0.0339	[-0.0352, -0.0325]
High Transfer Ratio: $\chi = 0.5$	0.0580	0.0313	[0.0310, 0.0318]
1960 Policy: $\tau_H = 0.229$, $\tau_k = 0.443$, $\chi = 0.224$	-0.0309	0.0030	[0.0016, 0.0044]
2004 Policy: $\tau_H = 0.27$, $\tau_k = 0.33$, $\chi = 0.42$	0.0407	0.0377	[0.0375, 0.0379]

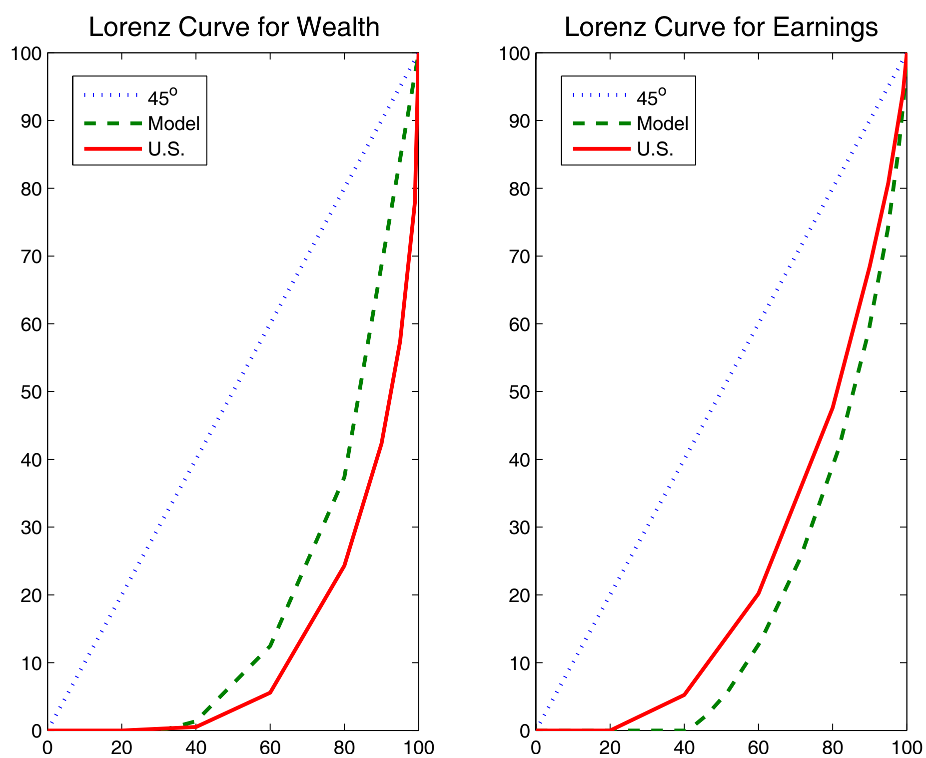
Notes: The entries in the table reflects the welfare gain (if positive) or cost, measured by (**??**), from the policy change. The "True" refers to the welfare measure based on the heterogeneous agent economy. The estimates are obtained by converting posterior parameter draws of the DSGE model.

Figure 1: U.S. Capital and Labor Tax Rates



Notes: The data are taken from Chen, Imrohoroglu, and Imrohoroglu (2007).

Figure 2: Lorenz Curves of Wealth and Earnings



Notes: The PSID statistics reflect family wealth and earnings in the 1984 survey.

Figure 3: Smoothed Shock Processes for Benchmark Economy ($T = 200$)

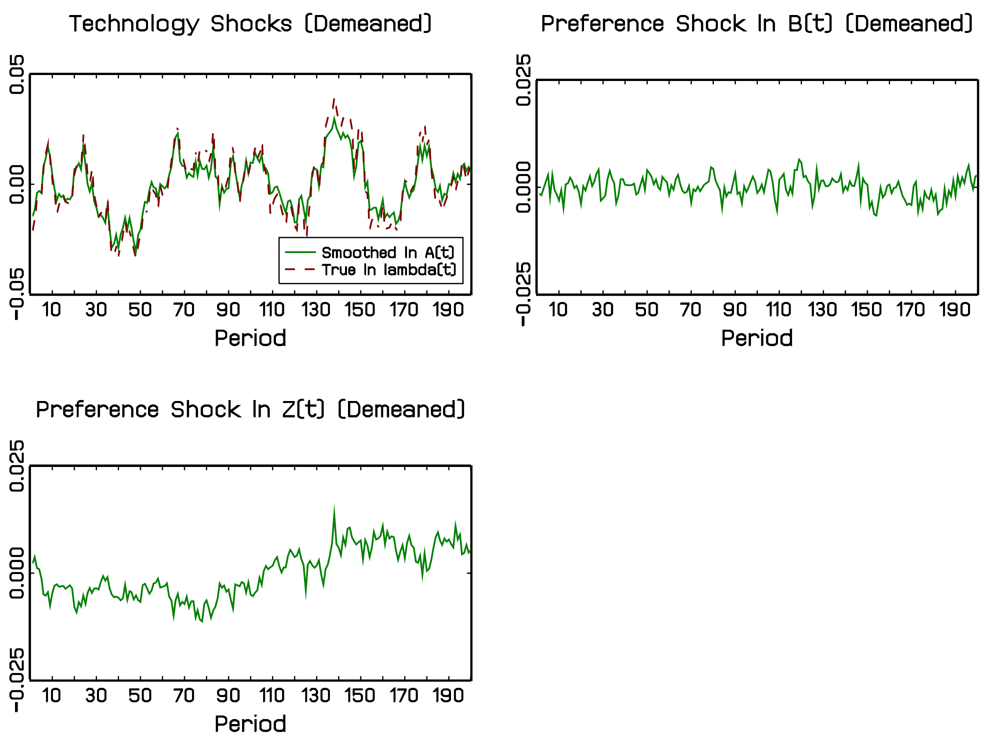
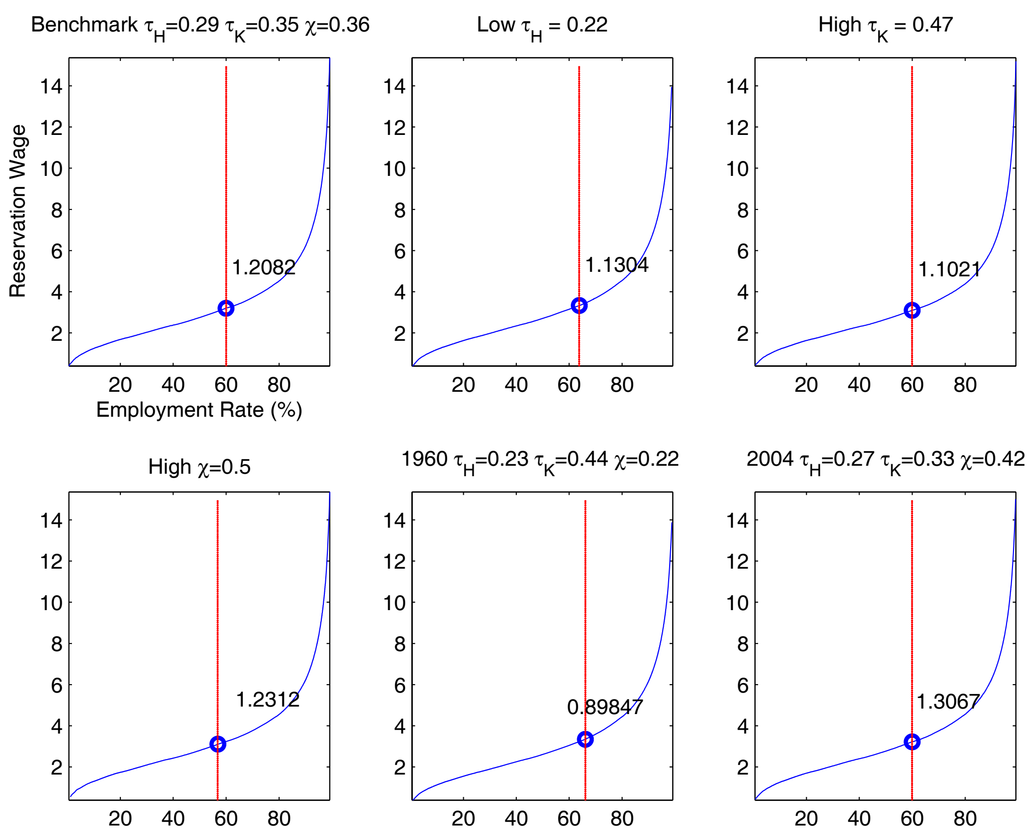


Figure 4: Employment Rate Based on the Reservation Wage Distribution



Notes: Each curve represents the employment rate (on the x-axis) at a given wage rate (y-axis). The vertical line denotes the steady state level of employment under the benchmark and the no-transfer policy regimes. The numbers in the plots indicate the elasticity of employment with respect to wages around the steady state employment rate.

A Derivations for the Representative Agent Model

First-Order Conditions: The first-order conditions (FOCs) associated with the Household Problem are:

$$\begin{aligned} \lambda_t &= \frac{Z_t}{C_t} \\ \lambda_t &= \beta \mathbb{E}_t[\lambda_{t+1}(1 + (1 - \tau_K) R_{t+1})] \\ H_t^{1/\nu} &= (1 - \tau_H) \frac{\lambda_t}{Z_t} W_t B_t^{1+1/\nu} \end{aligned}$$

Notice that the preference shock Z_t drops out of the labor supply function:

$$H_t^{1/\nu} = (1 - \tau_H) \frac{1}{C_t} W_t B_t^{1+1/\nu}.$$

The FOCs of the firms problem are provide in (4).

Steady States: We subsequently denote the deterministic steady state values by

$$\bar{H}, \bar{K}, \bar{\lambda}, \bar{C}, \bar{Y}, \bar{A}, \bar{B}, \bar{W}, \bar{G}, \bar{R}.$$

The steady state value of Z_t is equal to one. It is convenient to express the model in terms of ratios relative to steady state hours worked. The first-order conditions in the steady state become

$$\begin{aligned} \bar{R} &= \frac{1/\beta - 1}{1 - \tau_K}, \quad \left(\frac{\bar{H}}{\bar{B}}\right)^{\frac{1}{\nu}} = (1 - \tau_H) \frac{\bar{B}}{\bar{C}} \bar{W}, \\ \frac{\bar{K}}{\bar{H}} &= \left(\frac{\bar{A}(1 - \alpha)}{\bar{R} + \delta}\right)^{\frac{1}{\alpha}}, \quad \bar{W} = \alpha \bar{A} \left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha}. \end{aligned}$$

Hence,

$$\frac{\bar{H}}{\bar{B}} = \left(\frac{(1 - \tau_H)\bar{W}}{\bar{C}/\bar{H}}\right)^{\frac{\nu}{1+\nu}}.$$

Moreover, the production function can be expressed as

$$\frac{\bar{Y}}{\bar{H}} = \bar{A} \left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha}.$$

The government budget constraint leads to

$$\frac{\bar{T}}{\bar{H}} = \chi \left(\tau_H \bar{W} + \tau_K \bar{R} \frac{\bar{K}}{\bar{H}}\right), \quad \frac{\bar{G}}{\bar{H}} = (1 - \chi) \left(\tau_H \bar{W} + \tau_K \bar{R} \frac{\bar{K}}{\bar{H}}\right)$$

and the market clearing condition can be written as

$$\frac{\bar{Y}}{\bar{H}} = \frac{\bar{C}}{\bar{H}} + \delta \frac{\bar{K}}{\bar{H}} + \frac{\bar{G}}{\bar{H}}.$$

We can now write the consumption-hours ratio as

$$\begin{aligned}
\frac{\bar{C}}{\bar{H}} &= \bar{A}\left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha} - \delta\frac{\bar{K}}{\bar{H}} - (1-\chi)\left(\tau_H\bar{W} + \tau_K\bar{R}\frac{\bar{K}}{\bar{H}}\right) \\
&= \bar{A}\left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha} - (\delta + (1-\chi)\tau_K\bar{R})\frac{\bar{K}}{\bar{H}} - (1-\chi)\tau_H\alpha\bar{A}\left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha} \\
&= [1-(1-\chi)\tau_H\alpha]\bar{A}\left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha} - (\delta + (1-\chi)\tau_K\bar{R})\frac{\bar{K}}{\bar{H}}.
\end{aligned}$$

Hence, the steady state of hours worked is given by

$$\begin{aligned}
\bar{H} &= \bar{B}\left(\frac{(1-\tau_H)\alpha\bar{A}\left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha}}{[1-(1-\chi)\tau_H\alpha]\bar{A}\left(\frac{\bar{K}}{\bar{H}}\right)^{1-\alpha} - (\delta+(1-\chi)\tau_K\bar{R})\frac{\bar{K}}{\bar{H}}}\right)^{\frac{\nu}{1+\nu}} \\
&= \bar{B}\left(\frac{(1-\tau_H)\alpha}{[1-(1-\chi)\tau_H\alpha] - (\delta+(1-\chi)\tau_K\bar{R})\bar{A}^{-1}\left(\frac{\bar{K}}{\bar{H}}\right)^{\alpha}}\right)^{\frac{\nu}{1+\nu}} \\
&= \bar{B}\left(\frac{(1-\tau_H)\alpha}{[1-(1-\chi)\tau_H\alpha] - [\delta/(\bar{R}+\delta) + (1-\chi)\tau_K(\bar{R}/(\bar{R}+\delta))](1-\alpha)}\right)^{\frac{\nu}{1+\nu}}
\end{aligned}$$

Log-Linear Approximation: Denote the percentage gap from steady state value of each variable by

$$\widehat{H}_t, \widehat{K}_{t+1}, \widehat{\lambda}_t, \widehat{C}_t, \widehat{Y}_t, \widehat{A}_t, \widehat{B}_t, \widehat{W}_t, \widehat{G}_t, \widehat{Z}_t, \widehat{R}_t.$$

We obtain the following equations:

$$\begin{aligned}
[\bar{R}/(\bar{R}+\delta)]\widehat{R}_t &= \widehat{A}_t + \alpha\widehat{H}_t - \alpha\widehat{K}_t \\
\widehat{W}_t &= \widehat{A}_t + (\alpha-1)\widehat{H}_t + (1-\alpha)\widehat{K}_t \\
\widehat{\lambda}_t &= -\widehat{C}_t + \widehat{Z}_t \\
\widehat{\lambda}_t &= \mathbb{E}_t[\widehat{\lambda}_{t+1} + (1-\beta)\widehat{R}_{t+1}] \\
\nu^{-1}\widehat{H}_t &= -\widehat{C}_t + \widehat{W}_t + (1+\nu^{-1})\widehat{B}_t \\
\bar{Y}\widehat{Y}_t &= \bar{C}\widehat{C}_t + \bar{K}\widehat{K}_{t+1} - (1-\delta)\bar{K}\widehat{K}_t + \bar{G}\widehat{G}_t \\
(1-\chi)\widehat{G}_t &= \frac{\tau_H\alpha[\widehat{W}_t + \widehat{H}_t] + \tau_K(1-\alpha)[\bar{R}/(\bar{R}+\delta)]\widehat{Y}_t}{\tau_H\alpha + \tau_K(1-\alpha)[\bar{R}/(\bar{R}+\delta)]} \\
\widehat{Y}_t &= \widehat{A}_t + \alpha\widehat{H}_t + (1-\alpha)\widehat{K}_t \\
\widehat{A}_t &= \rho_A\widehat{A}_{t-1} + \sigma_A\epsilon_{A,t} \\
\widehat{B}_t &= \rho_B\widehat{B}_{t-1} + \sigma_B\epsilon_{B,t} \\
\widehat{Z}_t &= \rho_Z\widehat{Z}_{t-1} + \sigma_Z\epsilon_{Z,t}.
\end{aligned}$$

If $\chi = 0$ then $\bar{G} = 0$ and we compute the level of government spending rather than percentage deviations from a steady state that is zero.

B Aggregate Data Sources

Aggregate capital and labor tax rates are obtained from Chen, Imrohoroglu, and Imrohoroglu (2007). As a measure of hours we use the Aggregate Hours Index (PRS85006033) published by the Bureau of Labor Statistics. The remaining data series are obtained from the FRED2 database maintained by the Federal Reserve Bank of St. Louis. Consumption is defined as real personal consumption expenditures on non durables (PCNDGC96) and services (PCESVC96). Output is defined as the sum of consumption, consumption expenditures on durables (PCDGCC96), gross private domestic investment (GPDIC), and Federal consumption expenditures and gross investment (FGCEC96). Output, consumption, and hours are converted into per capita terms by dividing by civilian non-institutionalized population (CNP16OV). The population series is provided at a monthly frequency and converted to quarterly frequency by simple averaging. Finally we take the natural logarithm of output, consumption, and hours. We restrict the sample to the period from 1965:I to 2006:IV, using observations from the year 1964 to initialize lags. We remove linear trends from the log output and consumption series and demean the log hours series. To make the log levels of the U.S. data comparable to the log levels of the data simulated from the heterogenous agent economy, we adjust (i) detrended log output by the steady state output level in the heterogenous agent economy under the benchmark tax policy, (ii) detrended log consumption by the steady state output level in the heterogenous agent economy plus the log of the average consumption-output ratio in U.S. data, and (iii) demeaned hours by the steady state of log employment.

C Additional Tables and Figures

The following tables and figures summarize results for all policy experiments.

Table 8: posterior mean parameter estimates $T = 2,500$.

Table **??**: posterior mean variance decompositions.

Table **??**: steady states estimates.

Table **??**: Prediction of steady state changes $T = 2,500$.

Table C-1: Posterior Mean Parameter Estimates, $T = 2,500$

	Bench-mark	Lab. Tax Cut	Cap. Tax Raise	More Transfers	1960 Policy	2004 Policy
τ_H	0.29	0.22			.229	.269
τ_K	0.35		0.47		.443	.327
χ	0.36			0.50	.224	.417
r_A	2.77	2.56	2.74	2.84	2.53	2.75
ν	2.14	1.44	2.23	3.58	1.22	2.10
$\ln \bar{A}$	-0.26	-0.28	-0.25	-0.23	-0.30	-0.26
$\ln \bar{B}$	-0.32	-0.32	-0.31	-0.30	-0.31	-0.32
ρ_A	0.91	0.94	0.93	0.93	0.94	0.93
ρ_B	0.92	0.93	0.94	0.93	0.93	0.91
σ_A	.005	.006	.006	.005	.006	.006
σ_B	.003	.002	.003	.003	.002	.003
σ_Z	.003	.003	.003	.002	.002	.002

Notes: The following parameters are fixed during the estimation τ_H, τ_K, χ as tabulated, $\delta = 0.025$, $\rho_Z = 0.99$. Moreover, we used the re-parameterization $\beta = 1/(1 + r_A/400)$.

Table C-2: Posterior Mean Variance Decompositions, $T = 200$

		Bench-mark	Lab. Tax Cut	Cap. Tax Raise	More Transfers	1960 Policy	2004 Policy
τ_H		0.29	0.22			.229	.269
τ_K		0.35		0.47		.443	.327
χ		0.36			0.50	.224	.417
Output	B_t	0.05	0.04	0.06	0.10	0.04	0.08
	Z_t	0.05	0.02	0.07	0.03	0.02	0.03
Hours	B_t	0.33	0.46	0.40	0.46	0.49	0.49
	Z_t	0.05	0.03	0.07	0.02	0.02	0.03
Consumption	B_t	0.03	0.03	0.05	0.10	0.04	0.08
	Z_t	0.05	0.02	0.07	0.03	0.02	0.02

Table C-3: Steady State Estimates

	Benchmark			1960 Policy		
	"True"	Mean	90% Intv.	"True"	Mean	90% Intv.
Sample Size $T = 200$						
K	15.2	14.7	[14.2, 15.1]	15.4	14.5	[13.8, 15.2]
$H = E/3$	0.20	.200	[.199, .201]	0.22	.219	[.218, .220]
C	0.89	0.89	[0.88, 0.90]	0.90	0.89	[0.87, 0.91]
Y	1.48	1.46	[1.44, 1.48]	1.51	1.48	[1.44, 1.51]
G	0.21	0.21	[.207, .211]	0.23	0.23	[.223, .230]
Sample Size $T = 2,500$						
K	15.2	14.9	[14.7, 15.1]	15.4	14.9	[14.6, 15.1]
$H = E/3$	0.20	.200	[.200, .200]	0.22	.219	[.219, .220]
C	0.89	0.89	[0.89, 0.90]	0.90	0.90	[0.89, 0.91]
Y	1.48	1.47	[1.47, 1.48]	1.51	1.50	[1.49, 1.51]
G	0.21	.211	[.210, .211]	0.23	0.228	[.227, .229]

Notes: The "true" steady states are computed from the ergodic distribution of the heterogeneous agent economy. The estimates are obtained by converting posterior parameter draws of the DSGE model into steady states.

Table C-4: PREDICTIONS OF STEADY STATE CHANGES, $T = 2,500$

		Hours	Consumption	Output
Labor Tax Cut	"True"	6.30	7.61	3.50
$\tau_H = 0.22$	90 % Intv.	[3.24, 3.36]	[8.14, 8.27]	[3.24, 3.36]
Capital Tax Raise	"True"	-0.15	-2.69	-2.85
$\tau_K = 0.47$	90 % Intv.	[-0.34, -0.32]	[-3.52, -3.42]	[-3.98, -3.89]
More Transfers	"True"	-5.25	3.09	-2.17
$\chi = 0.5$	90 % Intv.	[-3.43, -3.31]	[1.56, 1.68]	[-3.43, -3.31]
1960 Fiscal Policy	"True"	9.95	1.75	2.60
$\tau_H = 0.229$, $\tau_K = 0.443$, $\chi = 0.224$	90 % Intv.	[5.66, 5.88]	[2.81, 3.04]	[2.80, 3.02]
2004 Fiscal Policy	"True"	-0.15	3.93	0.82
$\tau_H = 0.269$, $\tau_K = 0.327$, $\chi = 0.417$	90 % Intv.	[-0.22, -0.22]	[3.65, 3.67]	[0.35, 0.37]

Notes: The benchmark policy is $\tau_H = 0.29$, $\tau_K = 0.35$, $\chi = 0.36$. The entries in the table refer to percentage changes relative to the benchmark policy. "True" effects are computed from the means of the ergodic distributions of the heterogeneous agent economy. 90% Intv. are predictive intervals computed from the posterior of the representative agent model based on observations under the benchmark policy.

D Results Based on Efficiency Units of Hours

The following tables and figures summarize results obtained by replacing employment with efficiency units of hours.

Table **??**: posterior mean parameter estimates.

Table **??**: posterior mean parameter estimates (T=2000).

Table **??**: posterior mean variance decompositions.

Table **??**: policy predictions and outcomes (hours measured in efficiency unit).

Table D-1: POSTERIOR MEAN PARAMETER ESTIMATES, $T = 200$: HOURS MEASURED IN EFFICIENCY UNIT

	Bench-mark	Lab. Tax Cut	Cap. Tax Raise	More Transfers	1960 Policy	2004 Policy
τ_H	0.29	0.22			.229	.269
τ_K	0.35		0.47		.443	.327
χ	0.36			0.50	.224	.417
r_A	2.82	2.62	2.81	2.93	2.61	2.80
ν	0.55	0.45	0.56	0.62	0.40	0.54
$\ln \bar{A}$	0.00	0.00	0.01	0.00	0.00	0.00
$\ln \bar{B}$	-0.82	-0.83	-0.82	-0.81	-0.83	-0.82
ρ_A	0.89	0.94	0.92	0.91	0.94	0.93
ρ_B	0.90	0.88	0.89	0.89	0.88	0.90
σ_A	.007	.007	.007	.007	.007	.007
σ_B	.003	.002	.003	.003	.003	.003
σ_ζ	.002	.003	.003	.002	.002	.003

Notes: The following parameters are fixed during the estimation τ_H, τ_K, χ as tabulated, $\delta = 0.025$, $\rho_Z = 0.99$. Moreover, we used the re-parameterization $\beta = 1/(1 + r_A/400)$.

Table D-2: Posterior Mean Parameter Estimates, $T = 2000$

	Bench-mark	Lab. Tax Cut	Cap. Tax Raise	More Transfers	1960 Policy	2004 Policy
τ_H	0.29	0.22			.229	.269
τ_K	0.35		0.47		.443	.327
χ	0.36			0.50	.224	.417
r_A	2.75	2.54	2.71	2.82	2.51	2.73
ν	0.64	0.54	0.67	0.80	0.47	0.64
$\ln \bar{A}$	0.01	0.00	0.01	0.01	0.00	0.01
$\ln \bar{B}$	-0.81	-0.82	-0.81	-0.79	-0.83	-0.81
ρ_A	0.91	0.94	0.93	0.92	0.94	0.92
ρ_B	0.91	0.91	0.93	0.91	0.89	0.90
σ_A	.007	.007	.007	.007	.007	.007
σ_B	.002	.002	.002	.002	.002	.002
σ_ζ	.003	.003	.003	.002	.002	.002

Notes: The following parameters are fixed during the estimation τ_H, τ_K, χ as tabulated, $\delta = 0.025$, $\rho_Z = 0.99$. Moreover, we used the re-parameterization $\beta = 1/(1 + r_A/400)$.

Table D-3: Posterior Mean Variance Decompositions, $T = 200$

		Bench-mark	Lab. Tax Cut	Cap. Tax Raise	More Transfers	1960 Policy	2004 Policy
τ_H		0.29	0.22			.229	.269
τ_K		0.35		0.47		.443	.327
χ		0.36			0.50	.224	.417
Output	B_t	0.06	0.02	0.04	0.04	0.02	0.04
	Z_t	0.03	0.01	0.04	0.01	0.01	0.02
Hours	B_t	0.63	0.58	0.56	0.54	0.64	0.59
	Z_t	0.02	0.02	0.03	0.01	0.01	0.02
Consumption	B_t	0.06	0.01	0.04	0.04	0.02	0.03
	Z_t	0.04	0.04	0.04	0.02	0.01	0.02

Table D-4: Predictions of Steady State Changes, $T = 200$: Hours measured in efficiency unit

		Hours	Consumption	Output
Labor Tax Cut	"True"	6.30	7.61	3.50
$\tau_H = 0.22$	90 % Intv.	[1.52, 1.88]	[6.32, 6.70]	[1.52, 1.88]
Capital Tax Raise	"True"	-0.15	-2.69	-2.85
$\tau_K = 0.47$	90 % Intv.	[-0.19, -0.15]	[-3.49, -3.23]	[-3.93, -3.70]
More Transfers	"True"	-5.25	3.09	-2.17
$\chi = 0.5$	90 % Intv.	[-1.95, -1.57]	[3.12, 3.51]	[-1.95, -1.57]
1960 Fiscal Policy	"True"	9.95	1.75	2.60
$\tau_H = 0.229$, $\tau_K = 0.443$, $\chi = 0.224$	90 % Intv.	[2.64, 3.27]	[-0.20, 0.45]	[-0.19, 0.44]
2004 Fiscal Policy	"True"	-0.15	3.93	0.82
$\tau_H = 0.269$, $\tau_K = 0.327$, $\chi = 0.417$	90 % Intv.	[-0.13, -0.10]	[3.76, 3.80]	[0.45, 0.50]

Notes: The benchmark policy is $\tau_H = 0.29$, $\tau_K = 0.35$, $\chi = 0.36$. The entries in the table refer to percentage changes relative to the benchmark policy. "True" effects are computed from the means of the ergodic distributions of the heterogeneous agent economy. 90% Intv. are predictive intervals computed from the posterior of the representative agent model based on observations under the benchmark policy.