Financial Frictions, Aggregation, and the Lucas Critique

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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 generate data from a heterogeneous agent economy with idiosyncratic shocks and incomplete asset markets. We then estimate a DSGE model and document (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 inaccurate. (JEL: C11, C32, E32, E62)

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

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.

The tacit assumption underlying the DSGE model-based policy analysis has been that the parameters that characterize the preferences of representative agents and the production technologies of representative firms 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 laboratory 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]

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[1]Both the theoretical and the empirical importance of these frictions are by now widely recognized.

In this environment the distribution of household wealth and productivity is important for aggregate outcomes. The heterogeneous agent economy is calibrated to U.S. data, and we simulate observations on aggregate output, consumption, wages, and hours worked. Based on the simulated data we then 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.

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 parameters, 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

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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.

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 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 do not aggregate nicely due to the interaction between incomplete capital markets and indivisible labor. We then describe the various fiscal policy experiments that are considered subsequently and provide a benchmark calibration of our model economy.

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:

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

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 and supply 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 of the form

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

The first-order conditions associated with the static optimization problem are

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

In our notation R_t is return on capital in excess of capital stock depreciation δ. It is only this excess return that is subject to the capital tax τ_K. The physical capital stock evolves according to

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

where I_t is aggregate investment.

We specify the fiscal policy in this model such that transfers are constant over time and 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. The households' optimization problem can be represented recursively as follows. Dropping time subscripts, the value function for an employed household, denoted by V^E, is given by

$$
V^E(a, x; \lambda, \mu) = \max_{a' \in \mathcal{A}} \left\{ \frac{c^{1-\sigma} - 1}{1 - \sigma} - B \frac{\bar{h}^{1+\gamma}}{1 + \gamma} \right.
$$
$$
\left. + \beta E \left[\max \left\{ V^E(a', x'; \lambda', \mu'), V^N(a', x'; \lambda', \mu') \right\} \middle| x, \lambda \right] \right\} \tag{6}
$$

subject to the constraints

$$c + a' = a + (1 - \tau_H)Wx\bar{h} + (1 - \tau_K)Ra, \quad a' \geq \underline{a}, \quad \mu' = \mathbb{T}(\lambda, \mu),$$

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:

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

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.

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.

$$\bar{T} + G_t = \tau_H W_t \int x_t h(a_t, x_t; \lambda_t, \mu_t) \, d\mu_t(a_t, x_t) + \tau_K R_t \int a_t d\mu_t(a_t, x_t). \qquad (7)$$

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, that is, the utility from government purchases is additively separable from that of private consumption.

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:

$$K_t = \int a_t d\mu_t(a_t, x_t), \quad L_t = \int x_t h(a_t, x_t; \lambda_t, \mu_t) d\mu_t(a_t, x_t). \qquad (8)$$

Finally, the aggregate resource constraint can be expressed as

$$Y_t = \int c(a_t, x_t; \lambda_t, \mu_t) d\mu_t(a_t, x_t) + I_t + G_t. \qquad (9)$$

To solve for the competitive equilibrium in the model economy, we use the "bounded rationality" method developed by Krusell and Smith (1998). Agents make use of a finite set of moments of μ in forecasting aggregate prices. 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 transfers. We assume that transfers are a fixed fraction χ of steady state tax

revenues:

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

Here we use $\bar{z}$ to denote the steady state of an aggregate variable z_t and we dropped all t subscripts from household-specific variables as well as the distribution of household types.

Figure 1 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 20% to 30%. In 2005 government consumption expenditures were about 1,976 billion dollars and transfer payments amounted to 1,519 billion dollars. This leads to $\chi = T/(T+G) \approx 0.43$. At the same time GDP was 12,456 billion dollars and thus $T/Y \approx 0.12$ and $G/Y \approx 0.16$. For our benchmark fiscal policy we set both labor and capital tax rates to 20%, which is somewhat lower than around the year 2000, and let $\chi = 0.5$. With the caveat that in reality the government transfer payments are not made in a lump-sum fashion and distributed equally to all households, our χ value resembles the $T/(T+G)$ ratio in the data.

The tax experiment considered in Section 4 fall into two categories: changes in the composition of government spending and changes in tax rates. The composition of government spending creates an income effect and implicitly shifts the borrowing constraint. In addition to the benchmark value of $\chi = 0.5$ we consider the (extreme) values $\chi = 0$ and $\chi = 1$. We vary the tax rates by 10 percentage points, a magnitude that is commensurable with observed variations in tax rates over the post-war period. We consider a regime of low labor and high capital income taxes, $\tau_H = 0.1$ and $\tau_K = 0.3$, as well as a regime in which both tax rates are low: $\tau_H = 0.1$ and $\tau_K = 0.1$.

2.3   Calibration

We now summarize the choice of model parameters. 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.[3] 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 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.

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 2 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

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[3]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.

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 2.96, 10.88, 24.80, 63.06 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 0.15, 0.55, 1.23, and 3.18 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 15.60, 19.61, 23.91, and 31.27 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.[4]

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

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[4]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.

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

Much of the quantitative fiscal and monetary policy analysis is conducted with representative agent DSGE models, ignoring the effects that policy changes might have by altering the wealth distribution. In this section we describe such a DSGE model and will use it subsequently to estimate its parameters based on data from the heterogeneous agent economy. We then use the estimated DSGE model or predict the effects of alternative fiscal policies.

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:

$$\max \quad \mathbb{E}_t \left[\sum_{s=0}^{\infty} \beta^{t+s} Z_{t+s} \left\{ \ln C_{t+s} - \frac{(H_{t+s}/B_{t+s})^{1+1/\nu}}{1+1/\nu} \right\} \right] \tag{13}$$

$$\text{s.t.} \quad C_t + K_{t+1} = K_t + (1-\tau_H)W_t H_t + (1-\tau_K)R_t K_t + \bar{T}.$$

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:

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

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 (9). 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:

$$\bar{T} + G_t = \tau_H W_t H_t + (1 - \tau_K) R_t K_t. \tag{19}$$

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 $E_t = (1/\bar{h}) \int h(a_t, x_t; \lambda_t, \mu_t) d\mu_t(a_t, x_t)$, 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 data generated from the calibrated heterogeneous agent economy under the benchmark fiscal policy. We compare the estimates based on simulated data to estimates obtained based on U.S. data. 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 DSGE model based on data generated under different monetary 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.

4.1 Aggregation and Preference Shocks

We begin by estimating the DSGE model based on a sample of 200 observations from the heterogeneous agent economy under the benchmark fiscal policy. Posterior estimates of the latent shock processes $\ln A_t$, $\ln B_t$, and $\ln Z_t$ are plotted in Figure 3. Although the technology shock is the only aggregate in the heterogeneous agent economy, the DSGE model estimation detects both an intertemporal and an intratemporal preference shocks. For the technology shock, we overlay the "true" series $\ln \lambda_t$ with the Kalman smoother-based estimate of $\ln A_t$. While the two series are highly correlated, they are not identical. In particular $\ln A_t$ appears to be less volatile than $\ln \lambda_t$. In the heterogeneous agent economy households vary with respect to their idiosyncratic productivity. To satisfy the labor demand in booms, firms are forced to hire more of the less productive workers, which leads to a decline in average productivity. Vice versa, in recessions it is the low productivity workers who first get laid off. Thus, average productivity rises. The representative agent model captures this composition effect by a smoother productivity shock.

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 *a posteriori* 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 5. Jointly, the two preference shocks account for about 10% of the variation in output and consumption, and more than 55% 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 6, the estimated aggregate labor supply elasticity ($\hat{\nu} = 0.34$) based on U.S. data is much smaller, than the labor supply estimate ($\hat{\nu} = 2.00$) obtained from the simulated data.[5] A low aggregate labor supply elasticity implies that technology shocks only

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[5] A more detailed empirical analysis based on post-war U.S. data can be found in Rios-Rull, Schorfheide,

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 according to our estimates based on U.S. data and in the empirical literature more generally. 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 by examining the policy invariance of the parameter estimates, 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 exp(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 exp(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 proceed by comparing parameter estimates obtained from based on observations that are generated 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. We first contrast parameter estimates obtained under the benchmark fiscal policy ($\tau_H = \tau_K = 0.2$, $\chi = 0.5$) and an alternative policy in which the steady state transfers are zero ($\tau_H = \tau_K = 0.2$, $\chi = 0$) and subsequently consider other policy scenarios. To facility the comparison across policy regimes, the same productivity shock series is used under each fiscal policy.

Fuentes-Albero, Kryshko, and Santaeulalia-Llopis (2009).

Posterior inference for the DSGE model parameters is conducted based on 200 observations sampled from the benchmark and the no-transfer policy regime. Table 7 confirms for both policy regimes that the estimated representative agent models capture the steady states (or long-run averages) of key aggregate variables, such as capital, output, consumption, hours, interest rates, and government spending, in the heterogeneous agent economy. The reduction of the transfers generates a negative income effect for the agents in the model economy and pushes the low-skilled households closer to the borrowing constraint. In the representative agent model factor prices and the capital labor ratio are not affected by the removal of the transfers. But due to the increase in government purchases, a smaller fraction of output is available for consumption, which raises the marginal utility of consumption. At a given wage households are willing to work more. Overall, in the no transfer regime the level of output and capital is higher, but aggregate consumption is lower than in the benchmark regime.

Posterior means and 90% credible intervals for the DSGE model parameters are reported in Table 6. Most notably, the estimates of the aggregate labor supply elasticity ν, the level of productivity $\ln \bar{A}$, and the persistence of the intratemporal preference shock are markedly different in the sense that there is no overlap of the 90% Bayesian credible intervals. The drop in the estimated total factor productivity under the no-transfer policy is related to the rise in employment and hours work documented in Table 7. More of the low productivity workers are employed, which lowers the average level of productivity.

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 4. 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 both plots, 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 both fiscal policies, the elasticity of the schedule around the steady state employment rate is shown. Under the benchmark policy ($\tau_H = \tau_K = 0.2$ and $\chi = 0.5$), the elasticity of this schedule at the steady-state employment rate of 60% is 1.5. This elasticity is sensitive

to fiscal policy changes for two reasons. First, the shape of reservation wage distribution changes in response to changes in the wealth-earnings distribution. Second, the level of the steady state employment changes. Under the no transfer policy elasticity decreases to 0.8. While the estimated aggregate labor supply elasticities reported in Table 6 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: $\hat{\nu} = 2.0$ under the benchmark regime and drops to $\hat{\nu} = 0.6$ under the no-transfer policy. Aggregate labor supply elasticities are important for the propagation of technology shocks. Suppose the no-transfer policy is in effect. If one assumes incorrectly that $\nu = 2$ instead of 0.6, then one would predict that a one-percent increase in TFP raises output (employment) by 1.5% (0.8%) instead of 1.2% (0.4%). Finally, notice that the estimates of ν are markedly different from the parameter $\gamma = 0.4$ that appears in (1). This point has been stressed in Chang and Kim (2006).

Figure 5 depicts the estimated preference shock processes under the benchmark and the no-transfer policies. We subtract $\widehat{\ln \bar{B}}$ obtained under the benchmark policy from the smoothed $\ln B_t$ processes. Since the data sets used for the estimation were generated with the same random seeds, we deduce that the preference shock processes are not policy invariant. The visually most striking difference is the level shift of $\ln B_t$, which is also apparent in Table 6. However, the dynamics of the two series are also sensitive to the policy change.

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 the no-transfer policy studied previously, we also consider a full-transfer policy ($\tau_H = \tau_K = 0.2$, $\chi = 1.0$), a high-capital-tax policy ($\tau_H = 0.1$, $\tau_K = 0.3$, $\chi = 0.5$), and a low-taxes policy ($\tau_H = 0.1$, $\tau_K = 0.1$, $\chi = 0.5$). Compared to the benchmark policy, the full-transfer policy tends to decrease employment from 60% to 53%, and lower aggregate output and capital. The average labor productivity, however, increases as, less productive workers retreat from the labor market. The real interest remains more or less constant across different policies. If the capital income tax is raised to 30% in exchange for a 10% cut of the labor income tax, the lower labor income tax encourages labor supply, raising the aggregate employment rate

to 65%. This effect is even slightly more pronounced of the capital income tax rate is also lowered to 10%. Further details are provided in the Appendix.

Our goal is to predict the percentage change in average hours, consumption, and output, in response to a switch of the fiscal policy regime. This prediction is based on the representative agent model, estimated based on data from the benchmark policy regime. As before, we are using a realistic sample size of 200 observations. Our Bayesian framework allows us to compute predictive intervals for the policy effects. 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.

The results are summarized in Table 8. The "true" policy effect is computed from the simulation output of the heterogeneous agent economy, obtained under the various policies. For instance, the elimination of transfers raises hours by 11%, output by 4.7%, and lowers consumption by 7.4%. The predicted effect of this policy change on hours worked and consumption is much smaller than the actual effect. It can be verified from the steady-state relationships of the representative agent model provided in the Appendix that it is the high labor supply elasticity estimate under the benchmark policy that leads to an underprediction of the employment effect. The representative agent model over-predicts the increase in output, because it does not capture the drop in average productivity generated by the rise in employment. By and large, with the exception of the effect of the high capital tax policy on consumption, the actual policy effects lie well outside of the 90% predictive 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.

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 generated data from a calibrated heterogeneous agent economy in which households face idiosyncratic productivity shocks, borrowing constraints, and incomplete asset markets. We then estimated a DSGE model and found that incomplete markets and idiosyncratic

productivity shocks are captured by preference shocks in the aggregate 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 DSGE model parameters.

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Figure 1: U.S. Capital and Labor Tax Rates
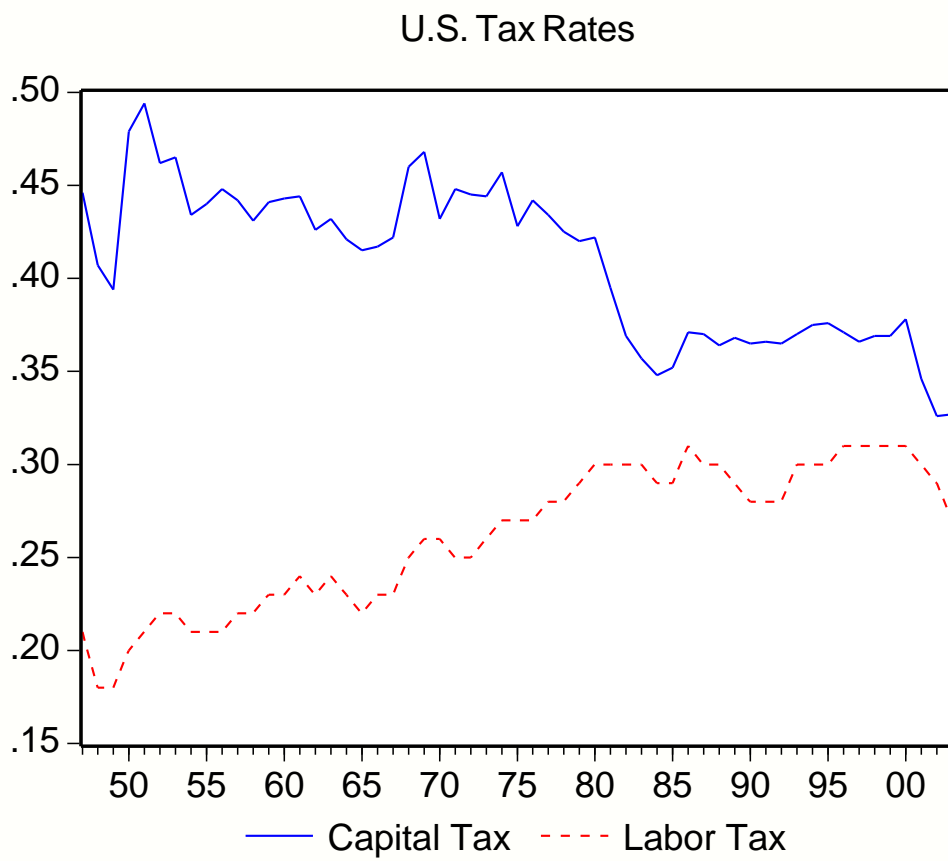
Notes: The data are taken from Chen, Imrohoroglu, and Imrohoroglu (2007).

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

Figure 2: LORENZ CURVES OF WEALTH AND EARNINGS
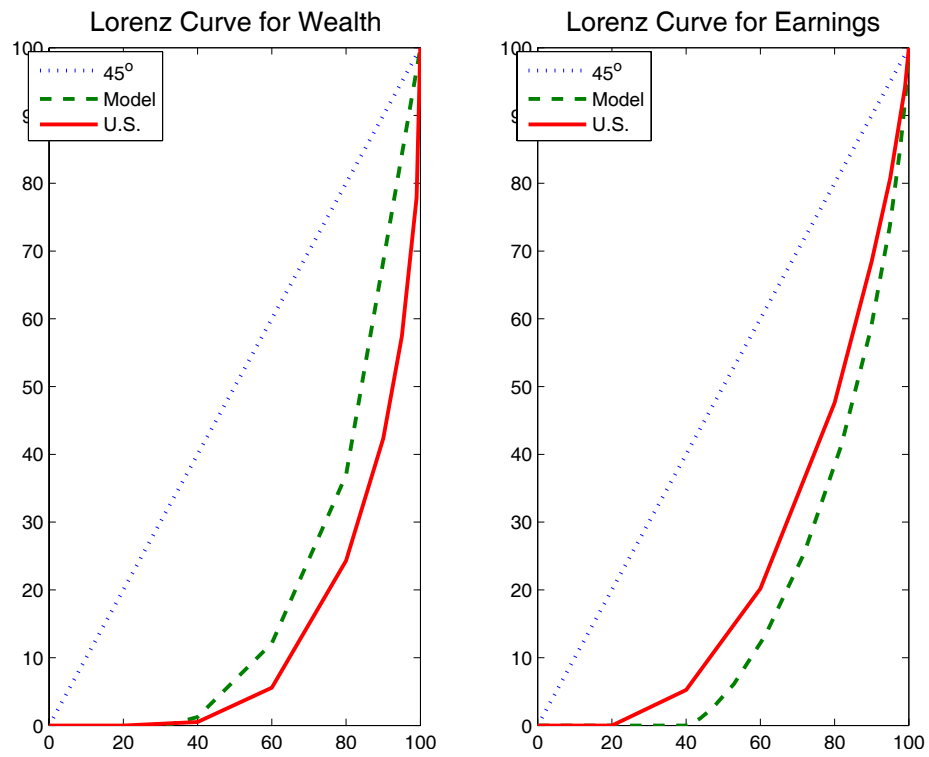
Notes: The PSID statistics reflect family wealth and earnings in the 1984 survey.

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	-1.71	2.96	10.88	24.80	63.06	100
Group average/population average	-.10	.15	.55	1.23	3.18	1
Share of earnings	9.60	15.60	19.61	23.91	31.27	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
$\sigma(\ln C)$	.022	.021
$\sigma(\ln H)$	.013	.042
$\sigma((\ln H)_{HP})$	.007	.018
$\mathrm{corr}(\ln Y, \ln C)$	0.89	0.83
$\mathrm{corr}(\ln Y, \ln H)$	0.77	0.56
$\mathrm{corr}(\ln C, \ln H)$	0.40	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.

Table 4: Prior Distributions for DSGE Model Estimation

Name	Domain	Density	Para (1)	Para (2)
r_A	$\mathbb{R}^+$	Gamma	4.00	2.00
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	0.01	4.00
σ_B	$\mathbb{R}^+$	Inv. Gamma	0.01	4.00
σ_Z	$\mathbb{R}^+$	Inv. Gamma	0.01	4.00

Notes: Para (1) and Para (2) list the means and the standard deviations for Beta, Gamma, and Normal distributions; the upper and lower bound of the support for the Uniform distribution; s and ν for the Inverse Gamma distribution, where $p_{\mathcal{IG}}(\sigma|\nu, s) \propto \sigma^{-\nu-1} e^{-\nu s^2/2\sigma^2}$. 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. We used the re-parameterization $\beta = 1/(1 + r_A/400)$.

Figure 3: Smoothed Shock Processes for Benchmark Fiscal Policy
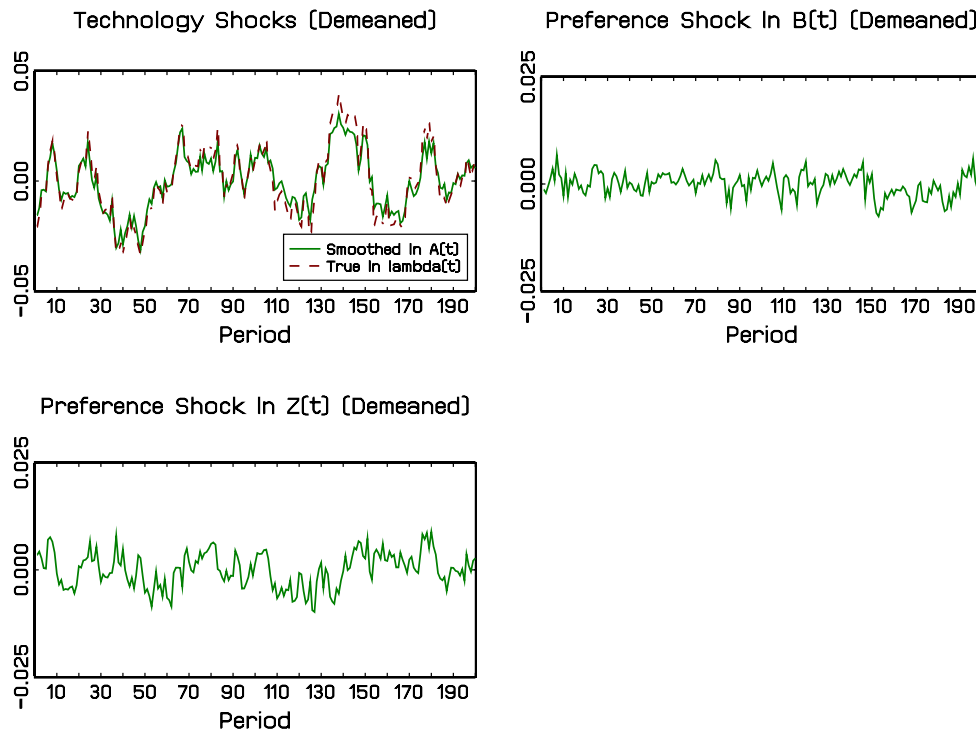
Table 5: RELATIVE IMPORTANCE OF PREFERENCE SHOCKS

	B		Z	
	Mean	90% Intv.	Mean	90% Intv.
Benchmark Economy				
Output	8	[5, 11]	2	[1, 2]
Consumption	7	[4, 11]	1	[1, 2]
Employment	54	[46, 63]	2	[2, 3]
U.S. Data				
Output	45	[21, 68]	5	[2, 9]
Consumption	47	[21, 75]	6	[1, 10]
Employment	98	[97, 99]	1	[0, 1]

Notes: The entries correspond to percentages.

Table 6: Parameter Estimates

|	Benchmark		No Transfers		U.S. Data	
	Mean	90% Intv.	Mean	90% Intv	Mean	90% Intv
r_A	3.44	[3.20, 3.68]	3.31	[3.20, 3.44]	3.70	[3.25, 4.22]
ν	2.00	[1.57, 2.38]	0.62	[0.48, 0.75]	0.34	[0.10, 0.60]
$\ln \bar{A}$	-0.27	[-0.28, -0.26]	-0.31	[-0.32, -0.30]	-0.25	[-0.27, -0.22]
$\ln \bar{B}$	-0.33	[-0.34, -0.32]	-0.35	[-0.36, -0.34]	-0.44	[-0.52, -0.37]
ρ_A	0.96	[0.96, 0.96]	0.94	[0.94, 0.95]	0.97	[0.96, 0.99]
ρ_B	0.95	[0.94, 0.97]	0.89	[0.86, 0.92]	0.98	[0.97, 0.99]

Table 7: Steady State Estimates

	Benchmark			No Transfers		
	"True"	Mean	90% Intv.	"True"	Mean	90% Intv.
K	14.9	14.5	[13.8, 15.2]	15.8	15.4	[14.9, 15.8]
$H = E/3$	0.20	0.20	[.198, .201]	0.22	0.22	[.221, .223]
C	0.98	0.97	[0.95, 0.99]	0.90	0.90	[0.88, 0.92]
Y	1.46	1.44	[1.40, 1.48]	1.53	1.51	[1.48, 1.54]
G	0.11	0.11	[.105, .110]	0.23	0.23	[.221, .229]

Notes: The "true" steady states are long-run averages computed from a large sample of observations from the heterogeneous agent economy. The estimates are obtained by converting posterior parameter draws of the DSGE model into steady states.

Figure 4: Employment Rate Based on the Reservation Wage Distribution
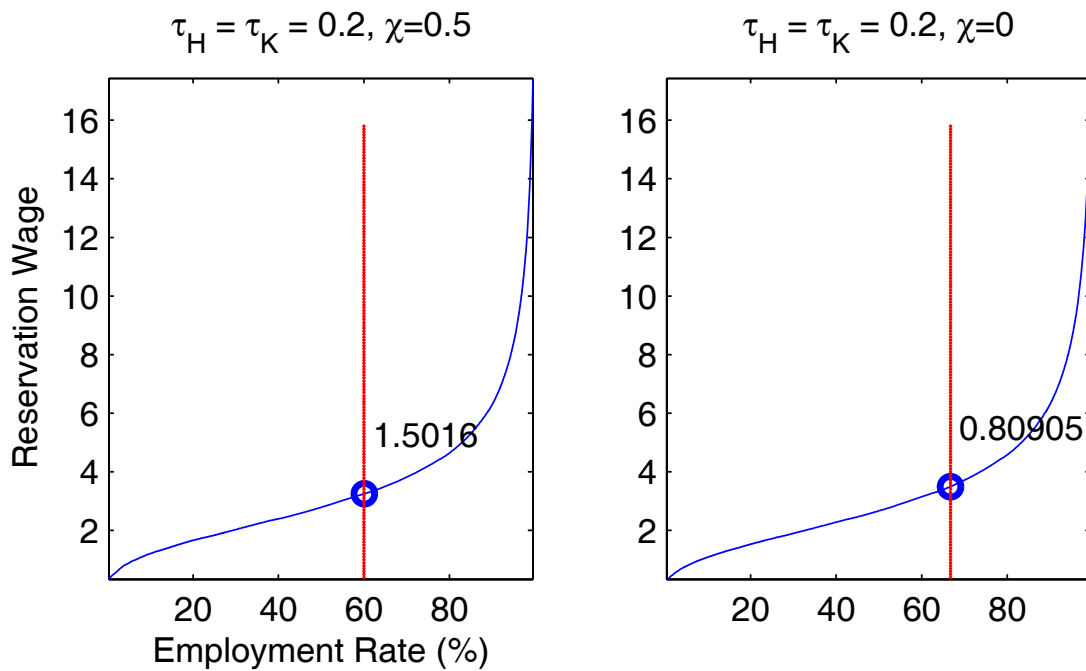
Notes: Each curve represents the employment rate (on the x-axis) at a given wage rate (y-axis). The vertical line denotes the steady state level of employment under the benchmark and the no-transfer policy regimes. The numbers in the plots indicate the elasticity of employment with respect to wages around the steady state employment rate.

Figure 5: PREFERENCE SHOCKS: BENCHMARK VERSUS NO-TRANSFER POLICY
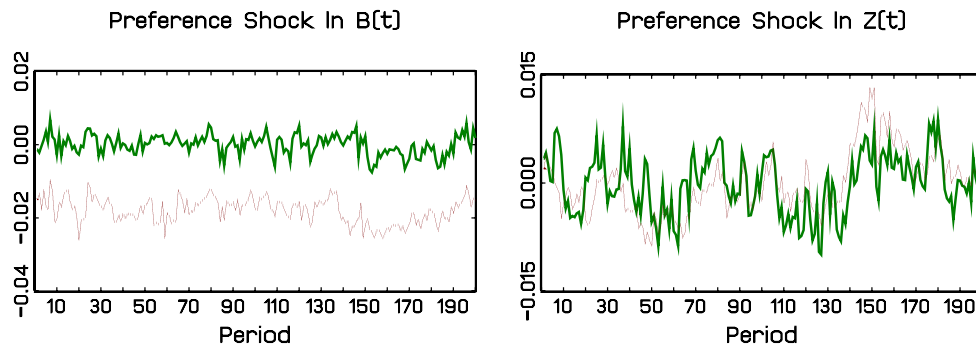
Notes: We depict smoothed estimates based on data generated under the benchmark policy (green, solid) and the no-transfer policy (red, solid). We subtract $\widehat{\ln \bar{B}}$ obtained under the benchmark policy from the smoothed $\ln B_t$ processes.

Table 8: PREDICTIONS OF STEADY STATE CHANGES

		Hours	Consumption	Output
No Transfers	"True"	11.0	-7.4	4.7
$\chi = 0.0$	90 % Intv.	[7.6, 8.8]	[-4.4, -3.3]	[7.6, 8.8]
Full Transfers	"True"	-11.5	6.3	-4.6
$\chi = 1.0$	90 % Intv.	[-7.2, -6.3]	[3.1, 4.1]	[-7.2, -6.3]
High Cap. Taxes	"True"	9.0	7.3	3.1
$\tau_H = 0.1$, $\tau_K = 0.3$	90 % Intv.	[4.2, 4.8]	[7.1, 7.8]	[1.8, 2.4]
Low Taxes	"True"	9.0	10.2	6.4
$\tau_H = 0.1$, $\tau_K = 0.1$	90 % Intv.	[4.8, 5.5]	[11.4, 12.2]	[6.8, 7.6]

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 C-1: steady states.

Table C-2: posterior mean parameter estimates.

Table C-3: posterior mean variance decompositions.

Table C-4: predicted volatilities of macroeconomic aggregates based on benchmark parameter estimates.

Figure C-1: employment rate based on the reservation wage distribution.

Table C-1: Steady States under Different Policies

	Bench-mark	No Transfers	Full Transfers	High Cap. Tax	Low Taxes
τ_H	0.2			0.1	0.1
τ_K	0.2			0.3	0.1
χ	0.5	0.0	1.0		
Employment Rate E	0.600	0.667	0.531	0.653	0.653
Capital K	14.97	15.84	14.18	15.43	16.86
Output Y	1.458	1.526	1.391	1.503	1.551
Labor Productivity Y/E	2.430	2.288	2.600	2.301	2.375
Interest Rate r	0.010	0.010	0.010	0.010	0.008

Table C-2: Posterior Mean Parameter Estimates

	Bench-mark	No Transfers	Full Transfers	High Cap. Tax	Low Taxes
τ_H	0.2			0.1	0.1
τ_K	0.2			0.3	0.1
χ	0.5	0.0	1.0		
r_A	3.444	3.311	3.478	3.033	3.100
ν	2.005	0.621	2.511	1.174	1.308
$\ln A_0$	-0.269	-0.313	-0.212	-0.306	-0.301
$\ln B_0$	-0.331	-0.348	-0.364	-0.324	-0.320
ρ_A	0.961	0.944	0.889	0.943	0.905
ρ_B	0.952	0.886	0.873	0.915	0.888
σ_A	0.006	0.006	0.005	0.006	0.006
σ_B	0.003	0.003	0.005	0.002	0.003
σ_Z	0.003	0.002	0.003	0.002	0.003

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 $\beta = 1/(1 + r_A/400)$.
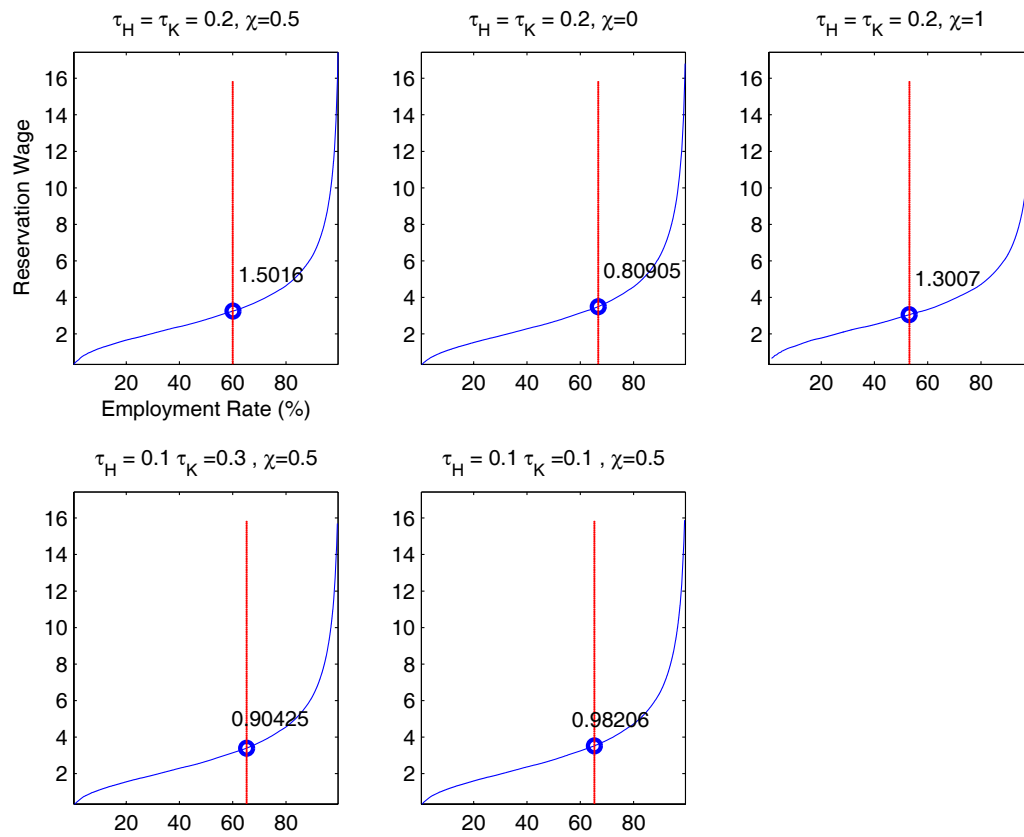
Table C-3: Posterior Mean Variance Decompositions

		Bench-mark	No Transfers	Full Transfers	High Cap. Tax	Low Taxes
τ_H		0.2			0.1	0.1
τ_K		0.2			0.3	0.1
χ		0.5	0.0	1.0		
Output	B_t	0.08	0.04	0.27	0.04	0.06
	Z_t	0.02	0.01	0.03	0.01	0.03
Hours	B_t	0.54	0.66	0.75	0.47	0.45
	Z_t	0.02	0.01	0.01	0.02	0.03
Consumption	B_t	0.07	0.03	0.25	0.03	0.06
	Z_t	0.01	0.01	0.04	0.01	0.04

Table C-4: PREDICTED VOLATILITIES OF MACROECONOMIC AGGREGATES

		Bench-mark	No Transfers	Full Transfers	High Cap. Tax	Low Taxes
τ_H		0.2			0.1	0.1
τ_K		0.2			0.3	0.1
χ		0.5	0.0	1.0		
Output	Actual	0.033	0.032	0.035	0.033	0.030
	Estimated	0.039	0.031	0.023	0.032	0.024
	Predicted	0.039	0.038	0.038	0.038	0.039
Hours	Actual	0.013	0.009	0.018	0.011	0.013
	Estimated	0.018	0.010	0.018	0.012	0.011
	Predicted	0.018	0.016	0.016	0.017	0.017
Consumption	Actual	0.022	0.023	0.020	0.022	0.021
	Estimated	0.027	0.022	0.014	0.021	0.014
	Predicted	0.027	0.028	0.029	0.028	0.028

Notes: The entries refer to standard deviations. *Actual* are calculated from 2000 observations of the heterogeneous agent economy. *Estimated* are posterior means of population standard deviations, computed from the estimated representative agent model. *Predicted* are posterior means of population standard deviations, obtained by modifying the policy coefficients in the estimated benchmark representative agent model.

Figure C-1: EMPLOYMENT RATE BASED ON THE RESERVATION WAGE DISTRIBUTION