

# Who Cares about Unemployment Insurance? \*

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## Abstract

Labor income and unemployment rates demonstrate considerable variation by skill. We construct a general equilibrium model with incomplete markets, search and matching friction, and ex-ante skill heterogeneity, that matches these facts. We use the model to study the role of skill-differences in choosing the generosity of an Unemployment Insurance (UI) system. Considering a proportional tax and replacement rate UI system, our model suggests an optimal replacement rate of 33%, while a model with ex-ante homogeneous workers calls for a much lower replacement rate of 15%. This is due to differences in both labor income and unemployment risk: labor income differences induce an incentive to redistribute while unemployment risk differences are necessary to make such a redistribution possible. Therefore, we claim that the higher optimal replacement rate is a consequence of the role of the UI system as a mean of redistribution across types.

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# 1 Introduction

It is well documented that labor market outcomes vary with workers' skills. For instance, in CPS data, the average unemployment rate of a college graduate in the US is 2.8%, while that of a high school dropout is 9.4%. In addition, the wage "college premium" for males in US data is around 80% (Krueger, Perri, Pistaferri, and Violante (2010)). Taken together, these observations indicate that lower-skilled workers face both higher unemployment risk and lower labor income.

Motivated by these observations, we construct a general equilibrium model with incomplete markets and ex-ante skill heterogeneity. This, in turn, generates heterogeneity in unemployment rates and wages. We then use the model to study the role of ex-ante skill heterogeneity in determining the generosity of an Unemployment Insurance (UI) system.

The main quantitative finding is that a model with ex-ante heterogeneity calls for a 33% replacement rate, more than twice as large as the one implied by a model with ex-ante homogeneous workers. The interpretation of this result revolves around the desire and the ability to use UI to redistribute resources *between* skill-types in the economy. Specifically, income differences generate consumption differences between types, hence generating an incentive for redistribution. We show, however, that in our model it is possible to use UI for such redistribution only when the unemployment rate differs across types.

The analysis builds upon a recent model suggested by Krusell, Mukoyama, and Şahin (2010) (henceforth, KMS) that has two key elements. First, unemployment in the model is endogenously determined by a search and matching friction as in Diamond (1982), Mortensen (1982), and Pissarides (1985) (DMP). Second, as in Bewley (undated), Huggett (1993), and Aiyagari (1994) (BHA), workers can self-insure only via risk free assets, and are subject to an ad hoc borrowing constraint. This implies that workers cannot perfectly insure their idiosyncratic income and unemployment risks, and that in equilibrium there is heterogeneity in asset holdings. As all workers in their model are ex-ante homogeneous, KMS abstract from issues of skill heterogeneity. To analyze the consequences of skill heterogeneity, we assume that the population is divided into types that permanently differ in their labor market characteristics.

Within this context we consider three sources of ex-ante heterogeneity among workers. These sources endogenously generate differences in unemployment rate and income across types. In particular, we consider workers who permanently differ in the level of productivity, the separation rate, and the cost of recruiting. These parameters have a direct effect on the cost and the surplus generated from a match, that in turn determine wages and firms' job creation decisions. The latter is

crucial in characterizing workers' job finding rates that together with the separation rates determine the unemployment rate for each type in equilibrium. In Section 2 we describe the model, and in Section 3 we describe the details of our calibration of these parameters, relying on US labor market data.

The quantitative results and interpretation are discussed in Section 4. We start with a model where all workers are ex-ante homogeneous, and find that the optimal replacement rate is relatively low at 15%. This echoes the finding in KMS, who highlight the tension between BHA and DMP type of models. On the one hand, the fact that workers cannot insure idiosyncratic risks, as in many models in the BHA framework, implies ex-post heterogeneity in consumption even among ex-ante identical workers. Absent any costs of reallocation, these models typically call for a high level of unemployment benefits, in order to equalize consumption among workers. On the other hand, the search and matching friction places an incentive cost of UI on labor demand. Specifically, in the DMP framework wages are determined by Nash bargaining, hence a more generous UI system improves workers' outside options, increases wages, and depresses firms' incentives to maintain vacancies. Therefore, more generous UI benefits imply a higher unemployment rate, and the optimal replacement rate should be zero. As in KMS, the relatively low optimal replacement rate suggests that with ex-ante homogeneous workers, the costs of UI outweigh the benefits.

In contrast, our model with ex-ante heterogeneous workers calls for a much higher replacement rate of 33%. Given the two sources of heterogeneity, what drives the difference in optimal replacement rates? We analyze this question by considering two counterfactual calibrations. First, we consider a calibration with heterogeneity in unemployment rates only. In this calibration, there are essentially no income differences. Then we consider a calibration that keeps the unemployment rate constant for all types, but maintains income differences. For both counterfactuals, the optimal replacement rate is low (15%) and identical to the one in the ex-ante homogeneous model. Hence we conclude that the higher replacement rate stems from ex-ante heterogeneity in *both* income and unemployment.

The interpretation of this set of results relies on UI as an instrument for between-types redistribution. We show that in the model, income differences generate an incentive to redistribute, and unemployment differences generate the ability to do so. To support this argument, we study consumption dispersion in the model, and associate higher consumption dispersion with a stronger incentive to equalize consumption across workers.<sup>1</sup> In this context, we first observe that when labor

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<sup>1</sup>This reflects the notion that under standard assumptions on risk aversion: (i) absent any costs of redistribution, a policy maker would choose equal consumption for all workers; and (ii) the larger the initial dispersion, the more social welfare to be gained from consumption equalization.

income is similar across workers, consumption dispersion is relatively low, even at low levels of replacement rates. For example, in the calibration with heterogeneity only in unemployment, the low income dispersion results in a very low consumption dispersion. This suggests that workers use their ability to self-insure and accumulate assets to insure the unemployment risk. It is therefore not surprising that the optimal replacement rate is low in this case: further increases of the replacement rate lowers aggregate output and consumption, while there is not much to be gained from further redistribution.

Once we consider the calibrations that involve substantial income differences across types, there is a much larger consumption dispersion. However, we show that absent differences in unemployment rates, and given that the only policy tool is a UI system that is based on proportional taxes and benefits, it is impossible to achieve any redistribution across types. The reason is that in this case the group of workers of a particular type pays in taxes exactly what it receives in unemployment benefits. Therefore we conclude that the realistic case with both income and unemployment heterogeneity is the one where the policy maker has a relatively strong *incentive* to redistribute, and the *ability* to do so.

In Section 5 we conduct three robustness exercises that provide further support to the argument that the role of UI in the model is redistribution. First, we extend the model to include a progressive tax system. When we calibrate the tax system to approximately match the US tax schedule, the optimal replacement rate is only 1% lower than the baseline. This is because the progressive tax system reduces consumption dispersion, but still leaves room for further redistribution. Second, we consider a calibration with heterogeneous discount factors that results in a more dispersed wealth distribution. Consistent with our interpretation, the optimal replacement rate is 37%, higher than the baseline. Third, we consider a model where workers can borrow, and show that borrowing results in a horizontal shift of the wealth distribution, but has practically no implication for consumption dispersion. Therefore, it is not surprising that the optimal replacement rate is unchanged.

This paper contributes to the literature by highlighting that the redistributive role of UI in the model is qualitatively and quantitatively important. In this respect, we stress two aspects. First, since redistribution across types can be done by using other policy tools, most notably by progressive taxation, we do not interpret the result as a policy prescription. Instead we indicate that such redistribution is an integral part of a common UI system. A careful analysis of the broader question of an optimal mix of redistribution policies requires enrichment of the model along a few dimensions. We briefly discuss these challenges in Section 5.1. Second, the inclusion of ex-ante

heterogeneity does not contradict existing findings with ex-ante homogeneity. Instead, ex-ante heterogeneity introduces another dimension for insurance “behind the veil of ignorance” that can be interpreted as redistribution across types.

Our paper is related to the large body of literature on optimal UI, where a policy maker trades-off insurance against incentives of workers and firms. Certain aspects of our analysis are closely related to a number of previous studies. First, as in Fredriksson and Holmlund (2001) and KMS, the incentive cost of UI operates through firm’s incentives to post vacancies. Second, a few previous studies theoretically analyze the redistributive aspects of UI specific contexts. Wright (1986) characterizes a voting equilibrium in a model with heterogeneity only in employment prospects, no ability to save, and no incentive issues. He shows that under certain conditions, the median voter would use the UI system to insure the ex-ante “high-risk” workers. Marceau and Boadway (1994) consider redistribution between high and low skill workers in a Mirrleesian economy. They argue that using a minimum wage policy coupled with a UI system can be welfare improving because it resolves the informational constraints hence allows for redistribution towards low skilled workers. In the law literature, Lester (2001) surveys some of the legal and policy aspects of UI, and describes some of the potential redistributive roles of UI. Third, quantitative analysis of models with ex-ante heterogeneity along similar dimensions can be found in Pallage and Zimmermann (2001) and Mukoyama and Şahin (2006). Pallage and Zimmermann (2001) consider the question of optimal UI with ex-ante heterogeneity in skills. Their focus and analysis are different from ours due to the fact that the choice of UI generosity is based on political, or voting considerations, rather than welfare. Their results indicate that it is the voting that matters for the determination of optimal UI, regardless of whether workers are ex-ante homogenous or heterogeneous. Mukoyama and Şahin (2006) consider the welfare consequences of business cycle fluctuations once skill differences are taken into consideration, and show that unskilled individuals experience a substantial cost associated with business cycle fluctuations.

## **2 The model**

The model consists of five central building blocks. First, workers belong to types that permanently differ in their labor income and unemployment rate. Second, unemployment is a result of a search and matching friction in the labor market. Third, heterogeneity within types arises from individual workers’ asset accumulation decisions. Fourth, a standard neoclassical production function determines the level of output produced by each type of workers. Finally, a government can choose a

replacement rate for unemployment insurance, and tax workers in order to keep a balanced budget.

Our analysis focuses on the stationary steady state of the model, thus we assume no aggregate risk.

## 2.1 Sources of Heterogeneity

There is a measure one continuum of workers in the economy. We assume  $N$  types of workers, where the fraction of type  $i \in \{1, \dots, N\}$  is  $\phi_i$ , and  $\sum_i \phi_i = 1$ . The fraction of workers of each type is constant. Types differ along three dimensions: (i) the productivity level  $z_i$ ; (ii) the separation rate  $\sigma_i$ ; and (iii) the cost of posting a vacancy for a worker of type  $i$ , denoted by  $\xi_i$ . These sources of heterogeneity endogenously generate income and unemployment differences across types.

Another dimension of endogenous heterogeneity arises through asset accumulation. Workers can save and partially insure against unemployment risk by holding risk-free assets. In equilibrium, there exists a non-degenerate distribution of asset holding, as in BHA models. This asset distribution also implies a wage distribution within types.

## 2.2 Matching and Market Tightness

We assume that a worker's type is observable and that the labor market is segmented by types. Accordingly, firms maintain type-specific vacancies ( $v_i$ ), and unemployed workers apply only to vacancies that correspond to their type. Let  $u_i$  denote the unemployment rate for type  $i$ , and assume that all unemployed workers search for jobs, such that the number of searchers in market  $i$  is  $\phi_i u_i$ . A constant returns to scale matching function,  $M(v_i, \phi_i u_i)$  determines the number of new type  $i$  matches in a period.

We define market tightness in market  $i$ ,  $\theta_i \equiv v_i / (\phi_i u_i)$ , as the ratio of the number of vacancies to the number of unemployed workers in market  $i$ . Thus, we denote the probability that a worker meets a vacant job by  $\lambda_i^w = \lambda^w(\theta_i)$  where  $\lambda^w$  is strictly increasing in  $\theta$ . Similarly, we let  $\lambda_i^f = \lambda^f(\theta_i)$  denote the probability that a firm with a vacancy meets an unemployed worker of the same type, where  $\lambda^f$  is strictly decreasing in  $\theta$ .

Finally, we assume that a type  $i$  match separates with constant and exogenous probability  $\sigma_i$  in each period, and that matches that are formed in the current period become productive in the next period. Denoting next period variables by a prime ( $'$ ), the evolution of type  $i$  unemployment rate,  $u_i$ , is

$$u_i' = (1 - \lambda_i^w)u_i + \sigma_i(1 - u_i)$$

## 2.3 Unemployment Insurance and Taxes

We consider an unemployment insurance policy that involves a single replacement rate  $h$  for all unemployed workers.<sup>2</sup> We assume that UI is financed by a proportional tax  $\tau$  on labor earnings - wages for the employed, and unemployment benefits for the unemployed.<sup>3</sup> The government sets  $\tau$  in order to keep a balanced budget:

$$\sum_i \phi_i [u_i \times h\bar{w}_i(1 - \tau) - (1 - u_i) \times \bar{w}_i\tau] = 0 \quad (1)$$

Note that both the replacement rate and the labor income tax are proportional to wages, rather than a lump-sum tax and transfer system. Therefore the UI system does not allow a trivial redistribution between high and low-income workers.

## 2.4 Asset Structure

Workers have access to two types of assets: capital ( $k$ ) and claims on aggregate profits (equity,  $x$ ).<sup>4</sup> The return on capital is the rental rate  $r$  net of depreciation  $\delta$ . The return on equity is  $\frac{d+p}{p}$ , where  $d$  denotes dividends and  $p$  denotes the price of equity. Workers cannot hold claims on individual jobs, hence they cannot insure the idiosyncratic employment risk that they face.

A standard no-arbitrage condition implies that the returns on holding capital and equity are equal.<sup>5</sup> As a result, workers are indifferent with respect to the composition of the two assets in their portfolios. This allows us to track the “total financial resources”,  $a \equiv (1 + r - \delta)k + (p + d)x$ , as a single state variable for each worker. In addition, there exists an ad-hoc borrowing constraint  $\underline{a}$ .

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<sup>2</sup>We model the actual unemployment benefit for an unemployed worker of type  $i$  as a constant replacement rate  $h$  times the *average* wage earned by an employed worker of type  $i$ ,  $\bar{w}_i$ . We use the average wage in order to avoid the need to keep track of workers’ individual histories. The wage functions presented in Section 4 suggest that there is little variation in wages *within* type  $i$ , and we verify in all numerical exercises that within each type the lowest wage is higher than the unemployment benefit.

<sup>3</sup>In the US, UI is financed by firms’ payroll taxes according to “experience rating” - firms that layoff workers more frequently pay higher tax rates. However, as shown by Card and Levine (1994) and argued by Ratner (2013), the experience rating system in the US is imperfect. To simplify, we abstract from experience rating.

<sup>4</sup>One interpretation of the claim to aggregate profits is that each worker holds a portfolio of all matches in the economy, regardless of type. Alternatively, we can allow workers to hold specific claims to profits that arise from each type of matches. In such a setting all firms would have the same return on their equity, hence workers are indifferent with respect to the composition of those types of equity.

<sup>5</sup>As the model doesn’t have aggregate risk, the equity price remains constant in equilibrium:  $p = \frac{d+p}{1+r-\delta}$ .

## 2.5 Workers

Let  $W_i(a)$  denote the value function of an employed worker of type  $i$ , who owns  $a$  assets. Similarly,  $U_i(a)$  denotes the value function of an unemployed worker of type  $i$  who owns  $a$  assets. Workers move between employment and unemployment according to the endogenous job finding rate ( $\lambda_i^w$ ), and the exogenous job separation rate ( $\sigma_i$ ). Workers take both probabilities parametrically.

Workers period utility is represented by an increasing and strictly concave function  $u(c)$ , and they discount future streams of utility by a discount factor  $\beta \in (0, 1)$ . Utility depends on consumption ( $c$ ) only, and there is no disutility from labor or home production. Hence the only flow benefit for an unemployed worker is UI benefits. In addition, search effort does not entail any cost. Therefore, all unemployed workers actively seek employment.

Workers allocate their available resources between consumption and accumulation of assets for the next period in order to maximize the discounted value of lifetime utility.

An employed worker begins a period with some level of assets ( $a$ ), and earns the period wage ( $w$ ) net of the tax rate  $\tau$ . The worker's wage - determined by Nash bargaining as explained below - is a function of the worker's type and asset holdings. Therefore, the beginning of period asset holdings  $a$  is the state variable of the problem. Denoting the inverse of the gross real interest by  $q \equiv \frac{1}{1+r-\delta}$ , imposing the borrowing constraint, and taking the transition probabilities into account, we specify the employed worker's problem:

$$\begin{aligned}
 W_i(a) &= \max_{c, a'} \{u(c) + \beta [\sigma_i U_i(a') + (1 - \sigma_i) W_i(a')]\} & (2) \\
 \text{s.t.} & : \\
 & c + qa' = a + w_i(a)(1 - \tau) \\
 & a' \geq \underline{a}
 \end{aligned}$$

An unemployed worker begins a period with some level of assets ( $a$ ), and receives unemployment benefits ( $h\bar{w}_i$ ) net of the tax rate  $\tau$ , where  $h$  is the economy-wide replacement rate and  $\bar{w}_i$  is the average wage of type  $i$  workers. Taking the transition probabilities into account, the unem-



ployed worker's problem is

$$\begin{aligned}
U_i(a) &= \max_{c,a'} \{u(c) + \beta [(1 - \lambda_i^w)U_i(a') + \lambda_i^w W_i(a')]\} \\
\text{s.t. } &: \\
& c + qa' = a + h\bar{w}_i(1 - \tau) \\
& a' \geq \underline{a}
\end{aligned} \tag{3}$$

## 2.6 Firms and Production

There is a large number of firms that can potentially maintain vacancies of any type, as long as they pay the type-specific cost  $\xi_i$ . The value of maintaining a vacancy of type  $i$ ,  $V_i$ , is

$$V_i = -\xi_i + q \left[ (1 - \lambda_i^f)V + \lambda_i^f \int J_i(a') \frac{f_i^u(a)}{u_i} da \right], \tag{4}$$

where  $V = \max \{V_1, V_2, \dots, V_N, 0\}$  because firms are free to choose between any of the  $N$  types of vacancies and being inactive. In equilibrium, firms post new vacancies until  $V_i = 0$  for all  $i$ .

Firms maximize the present discounted value of profits hence they discount future values by  $q$  - the market rate and the marginal rate of substitution of equity owners. The expected value of a match to the firm depends on the expected wage it will pay, that in turn depends on the worker's asset holdings. Therefore, the firm must form expectations regarding the asset holdings of the worker it will be matched with. To form these expectations, the firm takes into account that (i) next period's assets holdings of an unemployed worker depends on the current asset holdings; and (ii) matching is random, hence the firm's prediction is based on the current asset distribution of the unemployed. The integral in equation 4 captures this, where  $\frac{f_i^u(a)}{u_i}$  is the asset density of unemployed workers of type  $i$ .

In order to produce, a firm with a filled vacancy has to rent capital. Let  $k_i$  be the capital-labor ratio for matches of type  $i$ . We assume a standard neoclassical production function  $f(k)$  with  $f' > 0$ ,  $f'' < 0$ , such that a match of type  $i$  produces  $z_i f(k_i)$  units of output. With a frictionless capital market, all firms pay the same rental rate  $r$ , implying equal marginal products across firms. As a result, all firms of type  $i$  employ the same  $k_i$ .

The value of a filled job for a firm is the sum of the current period flow profits and the dis-

counted continuation value:

$$J_i(a) = \max_{k_i} \{z_i f(k_i) - rk_i - w + q[\sigma_i V_i + (1 - \sigma_i)J_i(a')]\} \quad (5)$$

We stress again that this value depends on the worker's asset holdings ( $a$ ) that affect both the wage in the current period (through bargaining), and the worker's asset holdings next period. The latter affects next period's wage, and therefore next period's continuation value of the match to the firm.

Finally, note that the dividend paid to equity owners every period is the sum of flow profits from all matches, net of the expenditure on vacancies. As flow profits depend on asset holdings of individual workers, this distribution is taken into account:

$$d = \sum_i \left[ \int \pi_i(a) f_i^e(a) da - \xi_i v_i \right] \quad (6)$$

## 2.7 Wage determination

The wage is determined by generalized Nash bargaining. We assume that firms cannot commit to wages, so that wages are set period by period. The Nash bargaining solution solves the problem:

$$\max_{\omega_i(a)} (W_i(a) - U_i(a))^\gamma (J_i(a) - V_i)^{1-\gamma} \quad (7)$$

where  $\gamma \in (0, 1)$  represents the bargaining power of the worker of any type.

The solution is a wage function  $\omega_i(a)$  for each type. The wage depends on assets because the value functions of workers,  $W$  and  $U$ , depend on their asset holdings.

## 2.8 Stationary equilibrium

A stationary equilibrium consists of:

1. A set of value functions  $\{W_i(a), J_i(a), U_i(a), V\}$
2. Consumption ( $c$ ) and asset accumulation policy functions ( $a'$ )
3. Prices  $\{r, \omega_i(a), p\}$
4. Vacancies  $v_i$  and demand for capital (per worker)  $k_i$

5. Tightness ratios  $\theta_i$  and implied probabilities  $\lambda_i^w$  and  $\lambda_i^f$
6. A replacement rate  $h$  and a tax rate  $\tau$
7. A distribution  $\mu$  over employment and assets
8. Dividends  $d$

such that:

1. Given the job finding probability  $\lambda_i^w$ , the wage function, and prices  $\{r, p\}$ , the worker's choice of  $c$  and  $a'$  solves the optimization problem for each individual. This results in the value functions  $W_i(a)$ , and  $U_i(a)$ .
2. Given the job filling probability  $\lambda_i^f$ , the wage functions, prices, the workers asset distribution, and the workers asset accumulation decisions, each firm solves the optimal choice of  $k_i$ . This results in  $J_i(a)$ .
3. Given the asset accumulation decision of unemployed workers, and the distribution  $\mu$ , firms compute the value  $V_i$ . With free entry,  $V_i = 0$
4. The asset market clears, and the aggregate demand for capital equals supply.
5. The wage functions  $\omega_i(a)$  are determined by Nash bargaining.
6. The government budget is balanced.
7.  $\mu$  is invariant and generated by  $\{\lambda_i^w, \sigma_i, \phi_i\}$ , and the asset accumulation policy functions.

We describe the computational algorithm in the Appendix.

### 3 Calibration

In this section we describe the calibration of the model that is used for the numerical analysis. We first describe a set of standard parameters that are kept constant across types. Then we describe in detail the calibration of parameters that govern the heterogeneity in the model.

One period is set to 6 weeks. The production function is  $f(k) = k^\alpha$ . We choose  $\alpha = 0.3$ ,  $\delta = 0.01$  and  $\beta = 0.995$  using the following calibration targets: a capital share of 0.3, an investment–output ratio of 0.2 and annual real rate of return on capital of 4.5%. The borrowing constraint  $\underline{a}$  is set at 0.<sup>6</sup> We use the utility function  $u(c) = \log(c)$ .

We assume a Cobb-Douglas matching function for all types:  $M(v_i, \phi_i u_i) = \chi u_i^\eta v_i^{1-\eta}$  so that

$$\lambda_i^w = \theta_i \lambda_i^f = \chi \theta_i^{1-\eta},$$

where  $\chi$  is the matching efficiency parameter.

Summarizing the literature that estimates the elasticity parameter  $\eta$ , Petrongolo and Pissarides (2001) establish a range of 0.5 - 0.7. Using more recent data, Brügemann (2008) finds a range of 0.54 - 0.63. In our benchmark calibration, we specify  $\eta = 0.6$  to be near the mid point of these ranges. We set the worker’s bargaining power parameter  $\gamma = \eta$ .<sup>7</sup> Finally, in our benchmark calibration we set the replacement rate  $h = 0.4$ , i.e. a 40% replacement rate, as is typically used to describe the replacement rate in the US economy.

### 3.1 Type-Specific Parameters

For the analysis in this paper, we identify skill with education. Specifically, using data from the monthly files of the Current Population Survey (CPS), we divide the labor force into four types: Less than high-school, High-school graduates, Some college, and Bachelor’s degree and over, denoted  $\{1, 2, 3, 4\}$ , respectively. We use data on labor force participants who are older than 25, reflecting the assumption that most people have made their education level choice by that age.

The top row of Table 1 describes the share of each type ( $\phi_i$ ), obtained by averaging over the share of each type in the labor force between 1994 and 2012.

Workers with different education levels differ substantially in terms of earnings and unemployment. The calibration of parameters governing productivity levels ( $z_i$ ), separation rates ( $\sigma_i$ ), and the cost of recruiting ( $\xi_i$ ) enables us to match these differences using our model.

To capture differences in earnings, we calculate “education premiums” using CPS data.<sup>8</sup> Specif-

<sup>6</sup>In the robustness section we verify that the main insights are unchanged when we allow for more relaxed borrowing constraints.

<sup>7</sup>In a textbook DMP model, setting  $\gamma = \eta$  guarantees that the allocation is constrained efficient, as this calibration satisfies the Hosios (1990) condition for efficiency. It is important to stress that satisfying this condition in our model does not guarantee efficiency. As Davila, Hong, Krusell, and Rios-Rull (2012) show, BHA models are not generally efficient because of externalities involved in the accumulation of capital.

<sup>8</sup>We use publicly available data on median usual weekly earnings by educational attainment for both men and

Table 1: Calibrated parameters

	Less than High-school	High-school	Some college	Bachelor's degree and over
Population share ( $\phi_i$ )	0.10	0.31	0.28	0.31
Productivity ( $z_i$ )	0.68	0.86	0.96	1.28
Separation rate ( $\sigma_i$ )	0.062	0.036	0.030	0.017
Vacancy cost ( $\xi_i$ )	0.51	0.74	0.88	1.37

ically, we calculate the premium for each type as the ratio of median wage for this type divided by the median wage of type 1. Averaging over all periods, the education premiums are 1.4, 1.6, and 2.5 for types 2, 3, and 4, respectively.

In the model, types' average wages are highly correlated with productivity levels. We calibrate the productivity levels  $z_i$  in order to match the education premium, normalizing the weighted average productivity to 1. These values are presented in the second row of Table 1.

According to CPS data, the average unemployment rates for types 1-4 equal 9.4%, 5.7%, 4.7%, and 2.8%, respectively. The immediate observation is that low skilled workers are more likely to be unemployed.

Similar to a standard DMP model, we use the (type-specific) unemployment evolution equations to express the steady state unemployment rate for each type:

$$u_i = \frac{\sigma_i}{\sigma_i + \lambda_i^w}$$

This term suggests that differences in unemployment risk across types can stem from different separation rates, different job finding rates, or both. In order to determine the appropriate weights we calculate the flows into and out of unemployment by educational attainment.<sup>9</sup> Interestingly, the data suggest that differences in the average unemployment to employment (UE) transition rates are minor and demonstrate no pattern that correlates with skill. On the other hand, the average employment to unemployment (EU) transition rates demonstrate a clear pattern - the lower the

women 25 years and older, for 1994:Q1 - 2012:Q4.

<sup>9</sup>We use CPS data for individuals who are 25 years and older, 1994:01-2012:07, and the same procedure as described in Elsby, Hobijn, and Şahin (2010), and Shimer (2012) to correct for short term unemployment.

type, the higher the EU transition rate.<sup>10</sup>

Motivated by the findings regarding the transition rate, we calibrate the model such that in the benchmark calibration, the entire difference in unemployment rates between types is due to the variation in the job separation rate. Specifically, we target a single equilibrium job finding rate of 0.6 per six-weeks period, consistent with the average monthly job finding rate in the data. Then we compute the implied separation rates such that the unemployment rate per type is consistent with CPS data.<sup>11</sup> The resulting values of  $\sigma_i$  are described in the third row of Table 1.

We use the set of zero profit conditions - one for each type of vacancies - to calibrate the recruiting cost parameters  $\xi_i$  as follows. In order to set the job finding rate at 0.6 for all types, we normalize the values of  $\theta_i$  to equal 1 for all types, and set the matching efficiency parameter  $\chi$  to equal 0.6. Given the productivity levels  $z_i$ , and the separation rates, we use the zero profit conditions to solve for  $\xi_i$  such that  $\theta_i = 1 \forall i$ . The resulting values of  $\xi_i$  are described in the fourth row of Table 1.

There is some empirical evidence supporting the result of vacancy costs that increase with education. Dolfin (2006) finds that the number of hours required for recruiting, searching, and interviewing workers depends on their education. Assuming that the skill of the workers engaged in recruiting is independent of the worker recruited, Dolfin (2006) finds that the cost of recruiting a high-school graduate is 50% higher than the cost of recruiting a lower skill worker, and that the cost of recruiting a worker with more than high-school education is 170% higher than the cost of recruiting a worker with less than high-school education. Barron, Berger, and Black (1997) report findings based on a variety of data sources, all clearly suggest that the cost of recruiting a worker is increasing in the worker's level of education.

## 4 Results

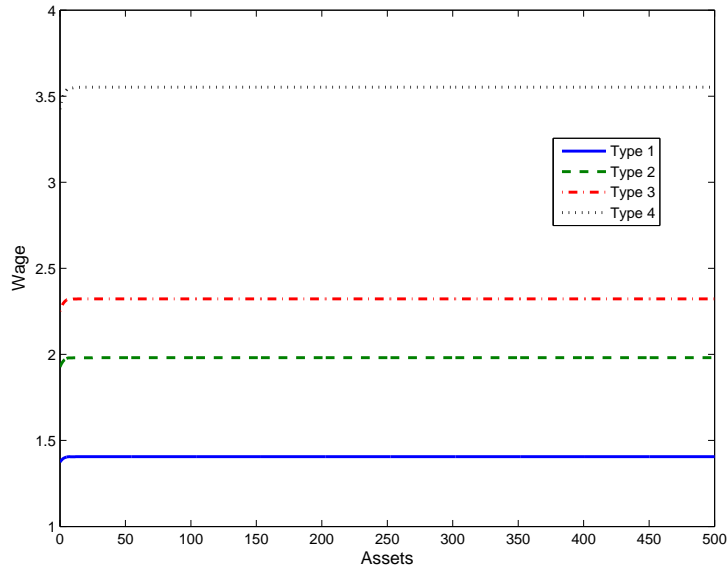
In this section we use the calibrated model to study the role of unemployment insurance in the economy. First, we show that as a result of ex-ante heterogeneity the wage distribution is more dispersed. Then we turn to analyzing the effects of changing the replacement rate. We implement this by computing the stationary equilibrium for a benchmark calibration with 40% replacement rate, as well as alternative economies with different replacement rates. For these computations, the only

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<sup>10</sup>The average monthly UE transition rates for the low skill to high skill types are: 49%, 47%, 48%, and 45%, respectively; the corresponding monthly EU transition rates are 3.7%, 2.0%, 1.7%, and 1.0%.

<sup>11</sup>When considering a model with ex-ante homogeneous workers, we calculate the weighted average of the separation rate, and apply it to all workers.

Figure 1: Wage functions, by type and asset holdings



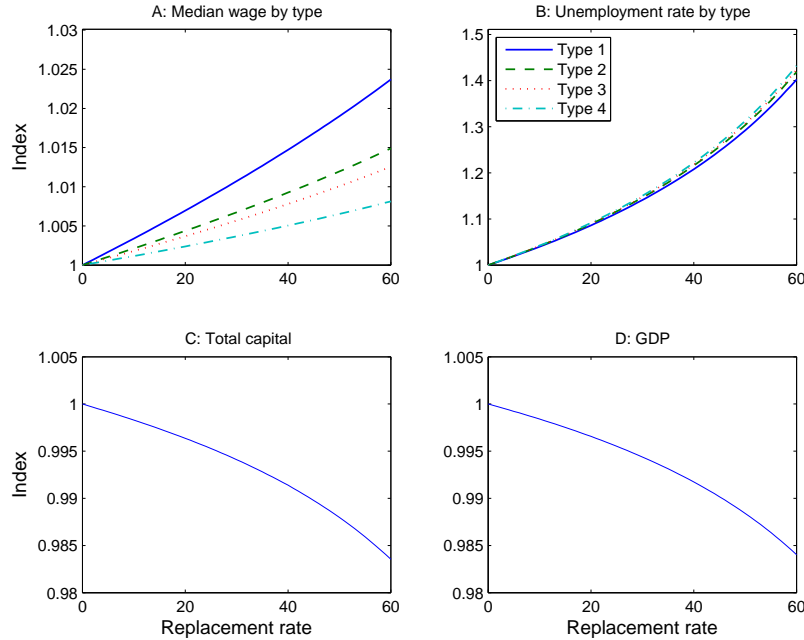
parameter we adjust other than the replacement rate is the tax rate that balances the government budget. We describe “comparative statics” for a few aggregate variables, and a welfare analysis that is instrumental for the choice of an optimal replacement rate. To clarify the role of UI in the model, we compare the results to those of a model with ex-ante homogenous workers, as well as calibrations where only some heterogeneity dimensions are present.

## 4.1 Wages

Figure 1 depicts the equilibrium wage functions for each of the four types at the 40% benchmark. Most of the wage dispersion in the economy arises from cross-type differences. Within types, wages are fairly inelastic with respect to assets.<sup>12</sup> The low variability of wages within types supports the simplification in characterizing unemployment benefits as a replacement rate times the average wage for a type. Note that the change in wages around the left tail is small, and the fraction of workers to the left of the kinks is 0.2%. Therefore, it is very unlikely that UI benefits are higher than a worker’s wage. Indeed, throughout our analysis, we verify that this is never the case.

<sup>12</sup>Krusell, Mukoyama, and Şahin (2010) and Bilts, Chang, and Kim (2011) present similar wage functions in similar frameworks.

Figure 2: The effect of replacement rate on steady state values



## 4.2 Analysis of Steady States

Figure 2 describes the changes of steady state values of several key variables as functions of the replacement rate. Panel A shows that all type-wise median wages increase with the replacement rate. In addition (and as expected), unemployment rates rise for all types, as shown in Panel B. Finally, Panels C and D show the decline in aggregate capital-labor ratio and aggregate output. These observations are consistent with a standard mechanism in DMP models: as increase in unemployment benefits improves workers’ outside option, increases the wage, depresses firms’ incentives to maintain vacancies, and increases unemployment. With lower employment, the aggregate demand for capital declines, and thus aggregate production declines. Taken together, this set of results verifies straightforward intuition – judging by aggregate variables, unemployment benefits are costly.

## 4.3 A Welfare Criterion and the Role of ex-ante Heterogeneity

To study the choice of an “optimal” replacement rate, we adopt the welfare criterion used in KMS, that also resembles that in Pallage and Zimmermann (2001). First, we calculate the stationary competitive equilibrium for economies that differ only in their replacement rate. We then move every individual, with her labor status and asset holdings, from the 40% benchmark economy to an



alternative economy that has a different replacement rate (in the range of [0%, 60%]). The welfare gain or loss for each individual from such a transition is characterized by  $\lambda$ , defined by:

$$E_0 \left[ \sum_{t=0}^{\infty} \beta^t \log ((1 + \lambda) c_t) \right] = E_0 \left[ \sum_{t=0}^{\infty} \beta^t \log (\tilde{c}_t) \right]$$

where  $c_t$  is consumption under the benchmark replacement rate ( $h = 0.4$ ) and  $\tilde{c}_t$  is consumption under an alternative replacement rate.

Finally, for each of the alternative replacement rates we integrate over the distribution of  $\lambda$  with respect to type, assets, and employment status in the benchmark replacement rate. This results in a measure of the aggregate welfare gain relative to the 40% benchmark. Alternatives that involve a positive aggregate gain are considered preferable over the benchmark. We refer to the replacement rate with the highest aggregate gain as the “optimal” replacement rate.

Before describing the results, we stress two issues regarding the welfare criterion. First, while admittedly we do not consider the entire transition path, we view this welfare criterion as preferable over summing steady state welfare levels for the different economies. The main reason is that a plain steady state comparison would miss the potentially important consequences of the short run savings adjustments along the transition to a new steady state. Second, note that the optimal choice is determined by the total gain. In this respect, our choice is consistent with the analysis in KMS, but departs from the analysis in Pallage and Zimmermann (2001) that considers voting patterns, and therefore emphasizes the fraction of population that gains from a change in UI policy.

The right panel of Figure 3 presents the welfare gain for our calibrated model. Relative to the 40% benchmark, welfare peaks at a 33% replacement rate. What we find striking is the sharp difference between the model with ex-ante *heterogeneous* workers and a model with ex-ante *homogenous* workers. In the latter, as presented in the left panel, welfare peaks at 15% - about half the level of the former.<sup>13</sup> In terms of welfare, relative to the 40% benchmark, eliminating the UI system results in a 0.11% welfare loss and a 0.07% welfare gain for the models with heterogeneous and homogenous workers, respectively. These welfare gains and losses are non-negligible. By comparison, using the same welfare measure in a different context, Mukoyama and Şahin (2006) find a welfare gain of 0.024% when eliminating business cycles.

Moreover, we observe that the aggregate welfare gain (0.11%) masks a much larger gains and

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<sup>13</sup>The model with ex-ante homogeneous workers essentially replicates KMS. When we consider ex-ante homogeneous workers, we calibrate the model such that the productivity level and the separation rate equal their weighted average counterparts in our model with ex-ante heterogeneity. As we consider a slightly different calibration than theirs, the optimal level of unemployment benefits is close to, but not exactly equal to the one in KMS.

Figure 3: Welfare gains



Notes: Aggregate welfare gains relative to an economy with 40% replacement rate. The gain is zero by construction at 40%. Left: a model with ex-ante homogeneous workers - highest welfare gain at 15% replacement rate. Right: the baseline model with ex-ante heterogeneous workers - highest welfare gain at 33% replacement rate.

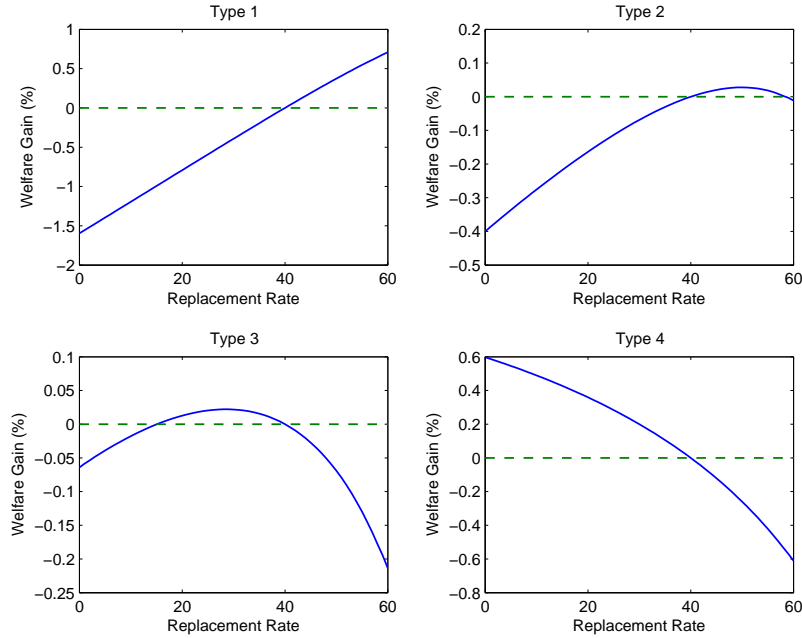
losses for specific types. The four panels of Figure 4 describe the welfare gain for each type in the model with heterogeneity. For instance, relative to the benchmark, eliminating the UI system results in a welfare loss of 1.6% for type 1, and a welfare gain of 0.6% for type 4. Clearly, types with low education prefer a higher replacement rate. The remainder of this section sheds light on the sources of this tension.

The analysis thus far suggests that ex-ante heterogeneity is quantitatively important with respect to the choice of an optimal replacement rate. In the context of the model, this result may stem from differences in productivity, differences in unemployment risk, or both. To better understand the role of UI in the model, it is important to distinguish between the two. We explore this by using two counterfactual calibrations, shutting down one source of heterogeneity at a time.

In the first counterfactual calibration, we eliminate differences in productivity and maintain the differences in separation rates. This results in an almost identical wage functions across types.<sup>14</sup> First, we recalibrate the model to match the same calibration targets for a 40% replacement rate. Then we change the replacement rate as before, and find the optimal replacement rate using the same welfare criterion. In this calibration, the optimal replacement rate is 15% - same as in the model with ex-ante homogeneous workers, and about half as high as the baseline model. In the second counterfactual calibration, we eliminate differences in unemployment, while keeping pro-

<sup>14</sup>While separation rates affect wages, the effect is minor.

Figure 4: Welfare gains, by type



Notes: Welfare gains, by type, relative to an economy with 40% replacement rate. The gain is zero by construction at 40%.

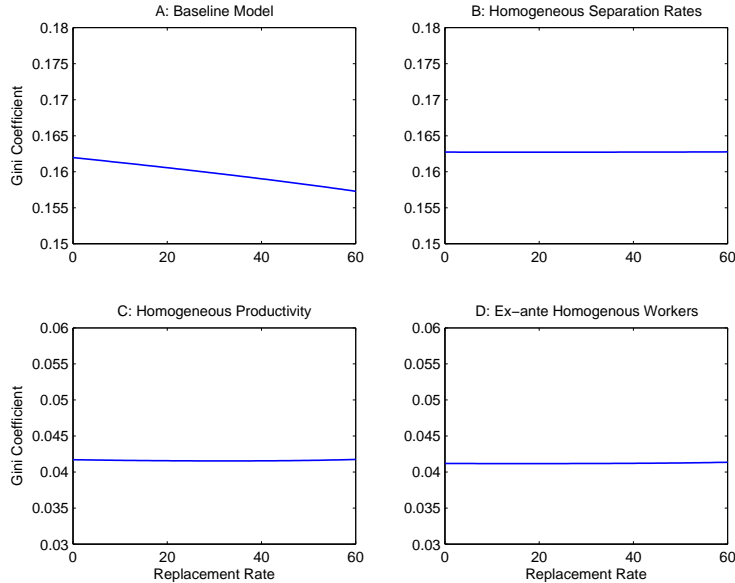
ductivity (wage) differences across types. In this calibration, the optimal replacement rate is again low at 15%.

Taking stock, we conclude that the relatively high optimal replacement rate in the baseline model is driven by heterogeneity in *both* productivity and separations, rather than any one in isolation. What drives this result? Our interpretation relies on the redistributive role of UI in the model. Specifically, we claim that heterogeneity in earnings generates a *desire* to redistribute resources across types, and heterogeneity in unemployment rates creates an *ability* for a UI system to redistribute.

#### 4.4 The Redistributive Role of UI

We think about the goal of redistributive policies as lowering the dispersion of consumption. Simply put, had redistribution been costless, a utilitarian policy maker would prescribe the same level of consumption to all workers. In our model we note three important features. First, using UI is costly, as illustrated by higher unemployment, lower capital, and lower GDP in Figure 2. Second, there is some heterogeneity in consumption *within* types that may justify some degree of reallo-

Figure 5: Gini coefficients by replacement rate



cation. Finally, our model introduces exogenous heterogeneity *between* types. This may add an incentive to redistribute resources between types in the economy. With this, our interpretation of the results is that given that UI is costly, the optimal replacement rate is affected by the desirability of redistribution and the ability to use UI to redistribute across types.

To illustrate this in more detail, we use measures of consumption dispersion for the aggregate economy and within types.<sup>15</sup> Figure 5 describes the Gini coefficient of consumption for the aggregate economy, for the range of replacement rate from 0% to 60%, for each of the calibrations we have considered thus far.<sup>16</sup>

First we observe that the two calibrations that involve no differences in productivity (Panels C and D) have substantially lower consumption dispersion. Moreover, consumption dispersion is low even when the replacement rate is zero. These results stem from two related reasons. First, the elimination of productivity differences implies that differences in wages are very small. In addition, workers in the economy self insure by accumulating assets. In an economy with complete ex-ante homogeneity, as in KMS, this implies a fairly condensed wealth distribution that leads to more equal consumption. In an economy where workers earn roughly the same income but face heterogeneous unemployment risk, high-risk workers accumulate more assets than low-risk

<sup>15</sup>We use consumption equivalents in order to capture a notion of welfare inequality.

<sup>16</sup>Analysis using coefficients of variation yields similar results.

Table 2: Gini coefficient by type ( $h = 0.00$ )

Type	Type 1	Type 2	Type 3	Type 4	Total
Ex-ante Homogeneous	0.041	NA	NA	NA	0.041
Baseline	0.073	0.051	0.044	0.029	0.160
No Heterogeneity in Productivity	0.059	0.046	0.041	0.031	0.042
No Heterogeneity in Separations	0.053	0.044	0.042	0.038	0.160

workers. For instance, in the context of our counterfactual economy, median wealth of “high-school dropouts” is 67% *higher* than that of “college graduates”. Once again, the implication is a fairly condensed consumption distribution, and a fairly weak incentive to redistribute.

In economies that involve heterogeneity in productivity, consumption is more unequal – Gini coefficients are around 0.16, compared to just over 0.04 in economies with equally productive workers. This is expected, as wage inequality translates to wealth and welfare inequality.<sup>17</sup> This finding also suggests that the rise in inequality is due to *cross-type* inequality, rather than *within-type* inequality. To further support this claim, in Table 2 we report the within-type Gini coefficients for the various calibrations at 0% replacement rate. First we note that all the within-type values are low, suggesting a relatively weak incentive for redistribution. In addition, for calibrations with heterogeneity in productivity, there is a substantial difference between the aggregate and type-wise Gini coefficients.

Given that heterogeneity in productivity provides a stronger incentive for redistribution, what is the role of heterogeneity in unemployment risk? Comparison of Panels A and B of Figure 5 reveals an important point regarding the *ability* of a UI system to redistribute. When all workers face the same unemployment risk (Panel B), adopting a higher replacement rate has no effect on consumption inequality. In contrast, when workers differ in their unemployment risk (Panel A), the UI system has the ability to lower consumption inequality.

To show this more explicitly, we analyze net transfers that an average worker of type  $i$  receives (i.e. unemployment benefits received minus taxes paid by the type). This can be expressed as  $\bar{w}_i [u_i h(1 - \tau) - e_i \tau]$ , where  $\bar{w}_i$  is the average wage of type  $i$ , and  $u_i$  and  $e_i$  are the unemployment and employment rates of type  $i$ . Balanced budget imposes that the sum of net transfers is zero:  $\sum_i \phi_i \bar{w}_i [u_i h(1 - \tau) - e_i \tau] = 0$ . When the unemployment rate equals  $\hat{u}$  for all types, balanced

<sup>17</sup>In the baseline economy with zero replacement rate, median assets of the top type is about 36% higher than the bottom type. In the economy with equal separation rates and zero replacement rate, median assets of the top type are more than double the median assets of the bottom type.

budget implies  $\sum_i \phi_i \bar{w}_i [\hat{u}h(1 - \tau) - (1 - \hat{u})\tau] = 0$ . Therefore, net transfers for each type, represented by the term in brackets, must equal zero. This implies that if the only policy tool is UI and there are no differences in unemployment risk, the policy maker has no ability to redistribute across types.

This reasoning explains the relatively low optimal replacement rate in an economy with ex-ante heterogeneous productivity levels and a homogeneous unemployment risk. In this economy, it is also the case that all types prefer a replacement rate that is 16% or lower.<sup>18</sup> Because there is no ability to redistribute across types, the dominant effect of increasing the replacement rate is the cost. The reason that the optimal replacement rate is not zero is because UI still provides some insurance within types, just like in the economy with ex-ante homogenous workers.

We summarize the role of heterogeneity in the model as follows. Heterogeneity in productivity makes redistribution across types more desirable. Heterogeneity in unemployment rates enables a UI system to redistribute resources across types. This explains why the optimal replacement rate is relatively high only in the calibration that includes both sources of heterogeneity, as in the data.

## 5 Robustness

In this section we provide further support for the redistributive role of UI in our model. In Section 5.1 we consider progressive taxation. In Section 5.2 we consider a more dispersed asset distribution. Finally, in Section 5.3 we allow borrowing.

### 5.1 Progressive Taxes

The main insight of the analysis thus far is that under some conditions, UI serves as a mean for redistribution. A natural candidate for redistribution is progressive taxation. In the context of our model, we study whether introducing a progressive tax system diminishes the redistributive role of UI. Specifically, we consider a tax system that consists of a progressive tax function, and a lump-sum transfer of the aggregate tax revenue. Note that both components of the tax system are redistributive as wages are heterogeneous. We integrate this tax system into our baseline model, recalibrate to match the calibration targets as above, and find the replacement rate that maximizes welfare gains (as before). Notice that wages in this calibration are targeted to *gross* wages so that net wages differ from the baseline model due to progressive taxation.

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<sup>18</sup>In contrast, in the baseline case, as illustrated in Figure 4, the type-wise optimal replacement rates are substantially more dispersed.

Following Gouveia and Strauss (1994) we use the tax function:

$$\tau_l(w) = a_0(w - (w^{-a_1} + a_2)^{-\frac{1}{a_1}}) \quad (8)$$

To calibrate the parameters of the tax function  $(a_0, a_1, a_2)$  we follow Castaneda, Diaz-Gimenez, and Rios-Rull (2003) and Erosa and Koreshkova (2007). Specifically, the two unit-free parameters  $(a_0$  and  $a_1)$  are set to their estimated values in Gouveia and Strauss (1994) for 1989. The value of  $a_2$  is set such that the average tax rate in the model corresponds to the one in the US economy.<sup>19</sup>

Surprisingly, the optimal replacement rate in this calibration is 32%, just 1 percentage point below the optimal rate without progressive taxes. Figure 6 provides intuition for this result. On the one hand, as plotted in the dotted line, progressive taxes reduce consumption inequality as expected. On the other hand, even with the progressive tax and lump-sum redistribution of *all* the tax proceeds, the Gini coefficient is fairly high, hence there is room for further redistribution. Moreover, if the tax system consists of (the same) progressive tax schedule, and no lump-sum rebates, then the effect of the progressive tax system on consumption inequality is more modest. The middle (dashed) line in Figure 6 illustrates this point by describing the Gini coefficients for different replacement rates in an economy with progressive taxes and zero lump-sum transfers.

We interpret the results in this section as support for the claim that redistribution is an integral part of a common UI system. However, it is important to note that this is not a policy recommendation or a normative statement. In order to have explicit policy recommendations, we would have to extend the model along several dimensions. First, we would have to consider an elastic labor supply decision, in order to capture the potential adverse effects of taxes on labor supply, as well as the effects of UI on search behavior. Second, we would have to consider a more accurate government expenditure plan. As shown above, the benefit from redistribution is highly sensitive to how proceeds are used. Finally, we would have to consider other existing welfare programs that aim at redistribution of resources in the economy. Therefore, we believe that the broader question of optimal mix of policy tools goes beyond the scope of this paper.<sup>20</sup>

<sup>19</sup>The resulting parameter values are 0.258, 0.768, and 0.237. Note that the 1989 tax function is a useful benchmark for later periods, as shown by Guner, Kaygusuz, and Ventura (2013).

<sup>20</sup>A more theoretical analysis of specific examples can be found in Boadway and Oswald (1983) who look at a mix of taxes, UI, and experience rating, and Marceau and Boadway (1994), who look at a mix of UI and minimum wages. Golosov, Maziero, and Menzio (2013) show that in the context of a specific directed search model, the constrained efficient allocation is such that unemployment benefits redistribute consumption between employed and unemployed workers, while the optimal tax system is regressive.

Figure 6: Consumption Gini - with and without progressive taxation

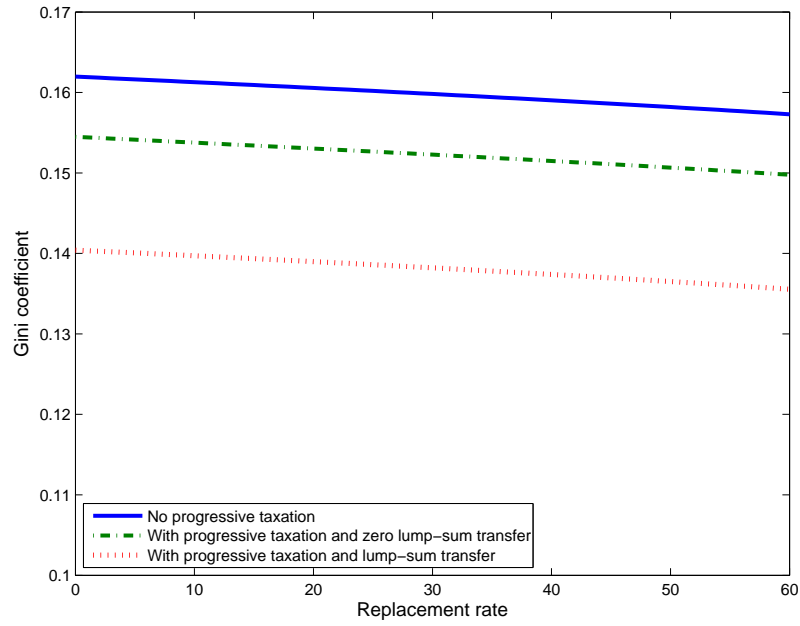
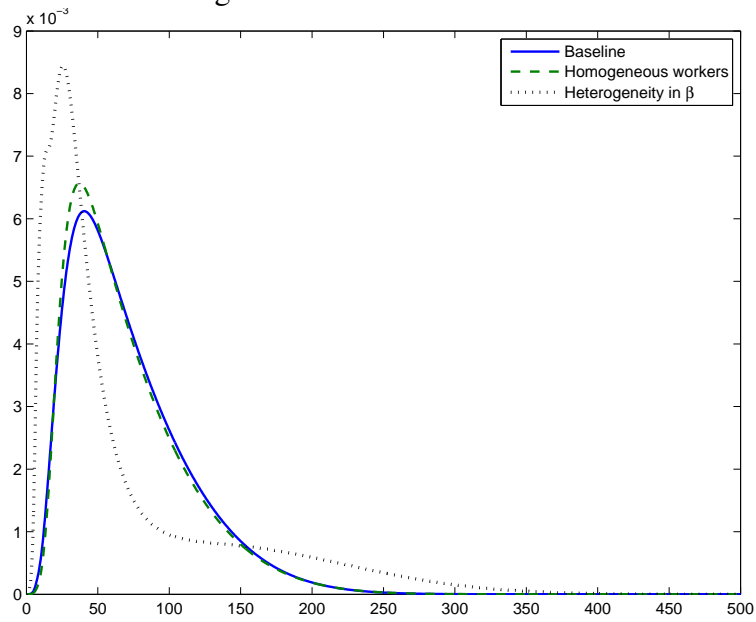


Figure 7: Wealth distribution





## 5.2 Heterogeneous Discount Factors

As in other studies in the BHA framework, the asset distribution in our baseline model is much less dispersed than the one in the data. To study the effect of a more realistic wealth distribution, we follow Krusell, Mukoyama, Şahin, and Smith (2009) and introduce heterogeneity in discount rates into the model. Specifically, this adds three new parameters to the baseline model, such that  $\beta$  varies by type. We calibrate these parameters such that we match the ratio of median wealth of types 2-4 relative to type 1 to their data counterparts.<sup>21</sup>

Figure 7 illustrates the resulting wealth distributions for a model with ex-ante homogenous workers, our baseline model, and the model with heterogeneous discount factors. The differences between the baseline model and the model with ex-ante homogenous workers are mild – the wealth distribution is slightly more dispersed and there is more mass at both tails. This contributes to more consumption inequality as described above. Once we integrate heterogeneous discount factors, wealth inequality is more substantial because college graduates hold most of the wealth in the economy. This is clear in the figure when looking at the mass on the right tail, and in Table 3, that describes the differences in median wealth for models with and without heterogeneity in  $\beta$ .

The welfare-maximizing replacement rate in a model with heterogeneous  $\beta$  increases to 37%. This is consistent with our reasoning that the role of UI in the model is a mean for redistribution across types.

## 5.3 Borrowing

In the context of BHA models, borrowing is perceived as important because it improves workers' self-insurance ability. In our model the main motive for UI is redistribution rather than insurance. Therefore, we do not expect that relaxing the borrowing constraint will have a large impact on the main insights. To support this, we alter the baseline model and allow workers to borrow up to two average monthly salaries. The main difference is the fact that the wealth distributions shifts to the left, reflecting the fact that workers borrow. However, the consumption Gini coefficient is almost identical to its value in the baseline model. It is therefore not surprising that the optimal replacement rate is unchanged at 33%.<sup>22</sup>

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<sup>21</sup>Outcault (2012) uses the Survey of Consumer Finances to report net worth by educational attainment. We use her reported data for 2001, the mid-point of our sample, as a calibration target.

<sup>22</sup>Repeating the exercise with a borrowing limit of four times the average monthly salary has no effect on these results.

Table 3: Median wealth by type: homogeneity vs. heterogeneity in  $\beta$

Calibration	Type 1	Type 2	Type 3	Type 4
Homogeneity in $\beta$	58.8	59.0	59.5	67.2
Heterogeneity in $\beta$	10.6	30.5	36.2	148.5

Notes: as the numeraire is an average of TFP, a more intuitive way to interpret the numbers in this table is to recall that the median wage in the model is roughly 2.5.

## 6 Concluding remarks

In this paper we argue that the redistributive role of UI is qualitatively and quantitatively important. We demonstrate this using a general equilibrium model that assumes *ex-ante* skill-heterogeneity that results in heterogeneity in labor income and unemployment risk. We calibrate the model to match key characteristics of US labor market data. In the model, heterogeneity in labor income makes redistribution desirable, while heterogeneity in unemployment risk enables redistribution using a UI system. The quantitative implications of this heterogeneity are substantial as it leads to about doubling of the optimal replacement rate from 15% to 33%. We show that both dimensions of heterogeneity are responsible for this difference, and use this to support the claim that the role of UI in the model is to redistribute resources across types.

Our model allows for a clear characterization of the economic forces that lead to the results. However, as we discuss in the paper, in order to make policy recommendations, we would have to enrich the model by including a number of features that are crucial for policy analysis. Such analysis is beyond the scope of this paper, as it must consider the broad question of the optimal mix of redistribution policies. Thus, while we abstract from normative statements in this paper, we believe that this is a challenging and interesting avenue for future research.

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## A Computation

In order to maximize her utility, the worker needs to know the entire wage function,  $\omega_i(a)$ . Therefore the algorithm we use aims at finding a *functional* fixed-point.

1. Start with an initial guess for  $\omega_i(a)$ ,  $r$ ,  $\theta_i$  and  $\tau$ .
2. Given the current guess for  $\theta_i$ , compute the probability of finding a job  $\lambda_i^w$  for each type and the associated unemployment level  $u_i$ .
3. Solve the workers' dynamic programming problem for each type of worker and for each level of assets. This gives both the value function and the capital accumulation path.
4. Given the employee's capital accumulation path and the wage associated with her next period's assets, calculate the firm's value function for each type of employee and for each asset level. This does not require the asset distribution, which is calculated in the next step.
5. Based on the optimal saving decisions of workers and the transitions probabilities between employment and unemployment, calculate the stationary distribution of assets for employed and unemployed workers of each type. Calculate the aggregate stationary distribution of workers across asset holdings given the weights  $\phi_i$  of each group and the measures of employed and unemployed workers within each group. This gives the total capital stock.
6. Update of the guess for  $\{\omega_i(a), r, \theta_i, \tau\}$  as follows.
  - Given the value functions of workers in step 3 and firms in step 4 perform Nash bargaining, which delivers an update for  $\omega_i(a)$ .
  - Use the total capital stock from step 5,  $u_i$  from step 2 and the first-order condition of each type of firm to compute  $k_i$  and  $r$ .
  - Use the firm's value and the distribution of assets over unemployed to calculate the expected value for the firm from a match. Given the vacancy cost and the value of a match we update  $\theta_i$  such that the value of a vacancy is zero. Note that we do not force  $\theta_i$  to be the same across types.
  - Given  $u_i, w_i(a)$  and the stationary distribution of workers across asset holdings of each type in step 5, update the tax rate so that the budget is balanced.