Worker Heterogeneity and Optimal Unemployment Insurance: The surprising Power of the Floor*

Simon J. Heiler†

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Abstract

Incentives to search for employment vary systematically with age and idiosyncratic labor productivity. These variations should be accounted for when designing UI policy, yet conditioning on related factors can be difficult or infeasible in practice. Using a life cycle model with endogenous human capital accumulation, idiosyncratic labor risk, and permanent differences in worker productivity, I analyse optimal UI policies. I find that for the U.S. an age-and-type-dependent policy generates welfare gains equal to 0.3 percentage points of consumption in all states and periods relative to a constant a replacement rate. Moreover, I demonstrate that about 80% of the gains from conditioning replacement rates on age only and about 60% of the welfare gains from conditioning on age and productivity can be generated by the current U.S. UI system. This can be achieved by substantially raising the benefit floor, a feature of the U.S. UI system that is largely ineffective in its current implementation.

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†University of Bonn, simon.heiler@uni-bonn.de, 53113 Bonn, Germany

1 Introduction

Unemployment insurance (UI) is an important component of most countries' social security systems. At the core of any UI system is a classic insurance-incentive trade-off: more generous UI benefits reduce search effort of the unemployed. This trade-off varies with the workers' characteristics. It has been proposed in the literature to use conditional UI benefits to account for differences in the trade-off that workers face at different stages of their lives (Michelacci and Ruffo, 2015) or at different positions in the wealth distribution (Rendahl, 2012). In practice, however, conditional benefits are difficult, if not impossible, to implement.

This paper analyses optimal UI policies when workers differ by age and ability. I find that an optimal age-and-ability-dependent policy generates welfare gains equivalen to a consumption increase by 0.31 percentage points. The paper's key finding is that a substantial fraction of these gains can be achieved through a simple, non-conditional policy consisting of a replacement rate on pre-unemployment earnings, a benefit floor and a benefit cap, much like the current U.S. UI system.

To quantify the effects, I use an OLG model with endogenous human capital accumulation and exogenous job separations calibrated to the U.S. economy. Human capital consists of a permanent ability type and experience, which is accumulated during employment (learning-by-doing) and depreciates during spells of unemployment. The policymaker maximizes expected lifetime utility of a worker at model entry. Optimal age-and-type-dependent replacement rates decrease with age and with ability. Rates for high-productivity workers start at ca. 50% and drop sharply to effectively zero around age 40. Rates for low-productivity workers start out even higher, at initially close to 100%, and decrease steadily over the lifecycle to ca. 40% at the end of the working life. The optimal non-conditional policy closely replicates these patterns in the first half of the working life, but provides higher UI benefits in the second half of the working life than optimal conditional rates. As mentioned above, the welfare gains from implementing optimal age-and-type-dependent replacement rates correspond to a 0.31 percentage point increase in consumption in all states and periods. The welfare gains from implementing the optimal rate, floor, and cap policy correspond to a 0.18 percentage point increase, or roughly 60% of the gains from the fully conditional policy.

These results are driven by endogenous human capital accumulation. Returns from working are two-fold: employed workers receive wages that can be consumed or saved and accumulates experience, which yields higher future wages. UI replaces lost income, but cannot compensate for foregone experience. Workers with highly productive human capital technologies thus have strong incentives to invest in experience in the first periods of their working life. Towards the end of their working life, they have accumulated significant savings towards and returns to additional experience are low. The optimal replacement rate for these workers is therefore initially high and drops significantly for older workers. Low ability workers, on the other hand, are less productive and experience more and longer unemployment spells. As a consequence, they accumulate less human capital and assets and are less able to self-insure against unemployment throughout their working lives. The optimal replacement rate for low ability workers therefore features less variation over the life-cycle than for high ability workers.

The non-conditional UI policy can replicate these patterns by introducing a non-linearity in the effective replacement rate. Low income workers are more likely to be affected by the benefit floor, high income workers are more likely to be affected by the benefit cap. As income correlates strongly with age and ability, younger and lower ability workers benefit from the floor more often and to a larger extent. Vice versa, older and higher ability workers' benefits are limited more frequently by the cap, reducing their effective replacement rate.

The paper proceeds as follows: Section 2 presents the related literature, section 3 presents empirical findings. Section 4 develops the laboratory economy for policy analysis, presents the baseline calibration and demonstrates the fit of the model to the data. Optimal conditional and non-conditional policies are discussed in section 5, including a discussion of the welfare effects. Section 6 concludes.

2 Related literature

This paper relates to the vast body of literature on optimal unemployment insurance in the tradition of Shavell and Weiss (1979) and Hopenhayn and Nicolini (1997). At the core of this literature is the moral hazard problem caused by the unobservability of search effort. The trade-off then is between providing public insurance where private markets are incomplete and (not) distorting the incentives to actively search for work when unemployed. While moral hazard is socially undesirable (as it implements inefficient search effort levels), providing insurance is socially desirable (as it partly resolves market incompleteness).

An important recent finding of this literature is that UI serves a double-role: it provides insurance against income risk and it provides liquidity to otherwise liquidity-constrained households (see e.g.Shimer and Werning, 2008). This in turn implies that longer unemployment duration in response to more generous UI policy is not unambiguously undesirable. When households are liquidity constrained, they search with higher than optimal effort. An increase in average unemployment duration after an increase in UI benefits could thus be caused by households being able to afford to search with optimal effort. Related to this, Chetty (2008) makes two observations: (i) the liquidity effect appears to be dominant for constrained households and (ii) the severity of the moral hazard problem in UI correlates with worker age. The findings indicate that the generosity of the UI system should account for a worker's age and level of savings.

A different strand of the literature focuses on the human capital channel. The importance of the channel has first been pointed out by Brown and Kaufold (1988). They analyze the interaction of UI policy with human capital investment decision and find a trade-off between providing more insurance and providing incentives to invest in human capital to self-insure.

Michelacci and Ruffo (2015) then combine the observation that response to UI correlates with age with the insight that the human capital channel is a key driver of this connection. They analyze optimal age-dependent UI policy using a structural model with an explicit age-structure and endogenous human capital accumulation through learning-by-doing. They find that raising UI replacement rates for younger workers and reducing replacement rates for older workers is welfare-enhancing. Their analysis, however, abstracts from any heterogeneity across workers other than age.

Focusing on differences in worker ability, but abstracting from age, Setty and Yedid-

Levi (2020) find that the UI system can redistribute resources from high skill to low skill workers. The key channel for this are differential equilibrium unemployment frequency and duration of low skill workers compared to high skill workers. If all workers pay into the insurance system in proportion to their earnings, this means that low skill workers benefit more from the system than high skill workers. If, in addition, the system features a cap on UI benefits, which is more likely to bind for workers with higher skill levels, redistribution from high to low skill workers further increases. They abstract from endogenous labor supply choice and endogenous educational choice or skill investment. Their framework, thus, does not feature feedback effects from higher UI benefit levels to labor supply or human capital investment.

The combination of worker heterogeneity with respect to age and productivity thus represents a gap in the UI literature. This paper contributes to closing this gap. The contribution of this paper is two-fold: First, I analyze the potential welfare gains from setting UI replacement rates when explicitly conditioning on age and productivity is feasible; second, I demonstrate that a sizeable share of the potential welfare gains can be obtained through an implementable (i.e. real-life) policies, inspired by the system currently in place in the U.S..

3 Empirical evidence

To demonstrate the role of age and idiosyncratic productivity in labor market policy, I attempt to answer two separate questions: First, do relevant differences by age and productivity exist in relevant labor market statistics? Secondly, does existing policy already address these differences by differential treatment? These questions will be addressed in the following sections.

Note that this exercise aims at isolating the combined effect of age and idiosyncratic productivity on important determinants of labor market prospects and policies. I therefore attempt to control for observable differences other than age and productivity, meaning that the results do not necessarily coincide with population averages.

Unemployment risk The goal of this section is to give an impression of what the U.S. UI system looks like when explicitly accounting for differences by age and education.

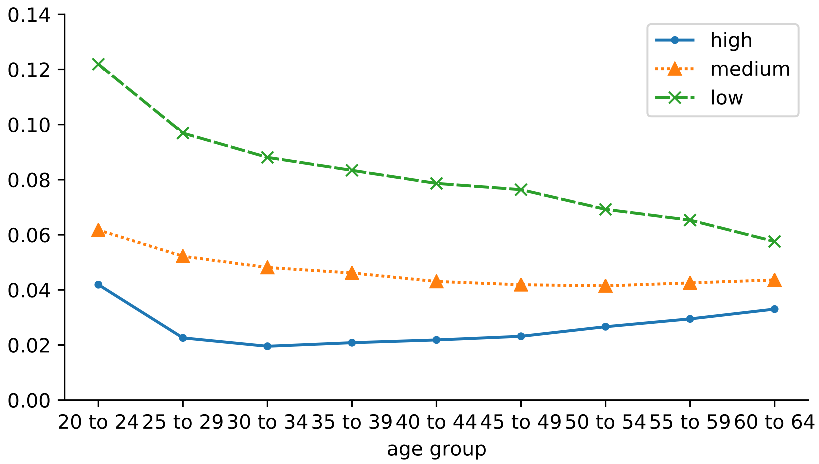


Figure 1: Labor market statistics by age group and educational attainment

Notes: Age profile of average unemployment probabilities by age group and education group (male CPS sample, 1989–2018).
Source: CPS basic monthly data.

Unemployment statistics are obtained from information on individuals' labor force status from the CPS. Throughout this analysis, idiosyncratic productivity is approximated by the educational attainment of an individual. For the sake of clarity in presentation and sufficiency of sample sizes, I group all observations into three groups: high school dropouts (*low*), high school graduates (*medium*), and college graduates (*high*).

In addition to the current labor force status, the structure of the CPS data allows us to observe changes in the labor force status from one month to the next for about 75% of the sample. Using this information, I compute three statistics capturing the dynamics of the U.S. labor market: unemployment probability, employed-to-unemployed transition probability and unemployed-to-employed transition probability. Average unemployment and transition probabilities by age group and education group are obtained in two steps: First, I predict individual probabilities using a probit model including an interaction term for age group and education group. Then, I compute conditional effects for each age / education combination.[1]

The resulting age-profiles of average probabilities are depicted in figure 1.

It is a well-known fact that unemployment risk decrease both with age and with education individually. When differentiating across both dimensions simultaneously, this

[1]For details, see Appendix A

relationship only partly holds true. While unemployment rates are decreasing by education for all age groups, they are no longer monotonously decreasing over the life-cycle for all education groups. To be precise, the rates of high school dropouts and high school graduates without college education fall over the life-cycle, yet the rates for the group with a college degree exhibit a slight u-shape.

Asset holdings The ability to self-insure against income loss from unemployment is determined in part by the savings of an individual or household. The assets-over-yearly-income-ratio measures how many years of income a household can substitute by decumulating assets. The CPS does not feature information on household asset holdings. To examine the ability to self-insure by age end education, I use data from the Survey of Consumer Finance (SCF). I pool observations from the SCF waves from 1989 to 2019 and compute median assets over median yearly income by age and educational attainment.

As can be seen in figure 2, assets increase faster over the lifecycle than income for all education groups, resulting in increasing age profiles of the assets-over-income-ratio. Moreover, households with more a highly educated reference person hold significantly more assets relative to income for all ages. Finally, note that the profile is mostly flat for high school dropouts where the median household does not have relevant buffer savings up until age 50, indicating that this group cannot effectively self-insure for most of the life cycle. The evidence indicates significant differences in the ability to self-insure, both with respect to age and education.

Returns to education and experience The positive correlation between both education and experience on earnings is well-documented, at least since Mincer (1958). The evidence on the interaction between education and experience with respect to income is less clear. In an early study, Psacharopoulos and Layard (1979) find steeper experience-earnings profiles for higher education groups.

To assess the relationship between work experience and earnings, I regress weekly labor earnings on tenure interacted with education, controlling for age, age squared, race, marital status, citizenship status and time and state fixed effects. The effects of tenure on earnings are substantial. Furthermore, they differ by education. To demonstrate average

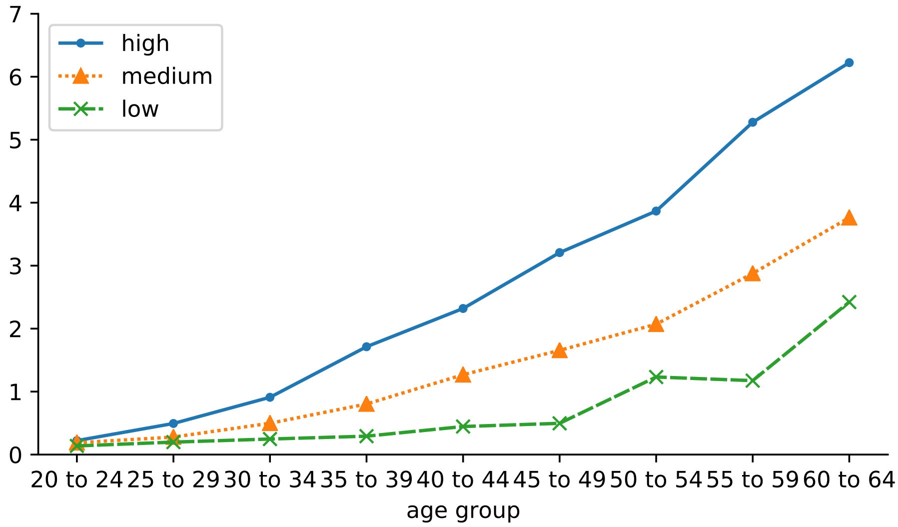


Figure 2: Median assets over median income by age and education

Notes: Age profiles of median assets over median yearly income by educational attainment. *Source:* SCF extracts 1989-2019.

marginal effects of tenure by education, I predict average weekly earnings by education and years of experience. Figure 3 depicts the results.

Earnings are increasing in education and in experience. Returns to experience, i.e. wage increases from additional experience, are positive but decreasing for all education groups, i.e. returns are high for workers with little experience and low for more experienced workers. Finally, while absolute increases are larger for workers with more formal education, relative returns are comparable across groups. The wage-experience profiles indicate that motives to invest in human capital accumulation depend strongly on the current level of experience for all education groups.

UI replacement rates The CPS does not include precise information on pre-unemployment wages or on UI replacement rates. Effective UI replacement rates are therefore obtained in a two-step procedure: first, pre-unemployment wages are imputed for all unemployed individuals in the sample; in a second step, benefits are then imputed based on imputed pre-unemployment wages, following the procedure first employed by Cullen and Gruber (2000).[2] Effective replacement rates are derived from imputed earnings and benefits. Average statistics by age and education are then again obtained from individual quantities

[2]For details on the procedure, see Appendix A.1; for further details regarding life-cycle profiles of imputed earnings and benefits, see Appendix A.2

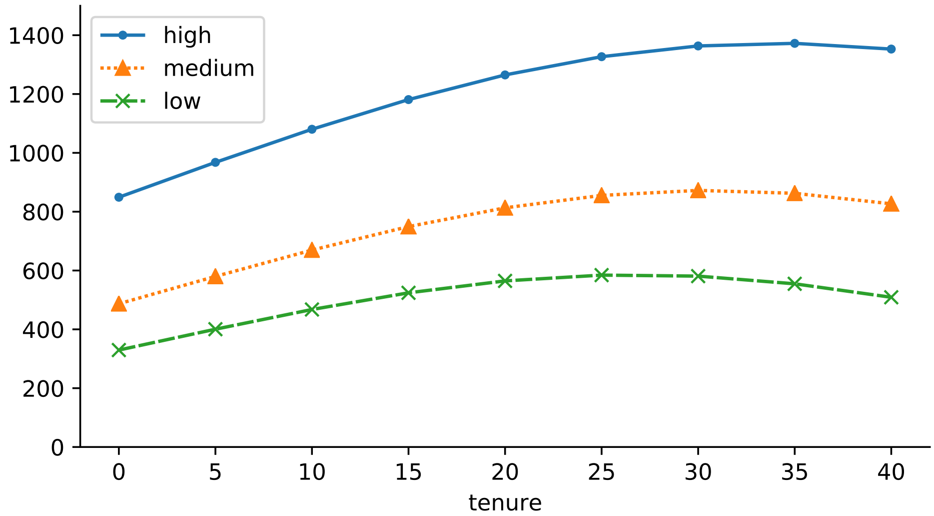


Figure 3: Average weekly earnings by years of experience and education

Notes: Age profiles of average weekly earnings by tenure and educational attainment. *Source:* CPS Tenure Supplements (2002-2018).

by regressing on observables and predicting average conditional effects by age group and education group. Figure 4 depicts average effective replacement rates by age group and education group.

To explain the shape of the profiles, recall one of the key features of the current system: the benefit cap. Naturally, individuals belonging to a group with higher average earnings are more likely to be affected by these caps than individuals belonging to a group with lower average earnings. This has two important implications: (i) differences in benefits between education groups are smaller than differences in earnings, i.e. age profiles are closer together, and (ii) the ages during which an individual is likely affected by the cap are different between education groups, i.e. age-profiles exhibit different shapes over the life-cycle. In other words, while average benefits for the low education group exhibit a scaled profile of average earnings, the age-profile for the high education group is only slightly higher (much less than for earnings) and mostly flat. In combination, this translates into substantial differences in the age-profiles of replacement rates. Because the low education group is mostly unaffected by benefit caps, the replacement rate is almost constant over the life cycle for this group. In contrast, more highly educated individuals are more likely to be affected even in young ages, yielding a lower average replacement rate. Moreover, with growing average earnings over the life-cycle, they become even more likely to be

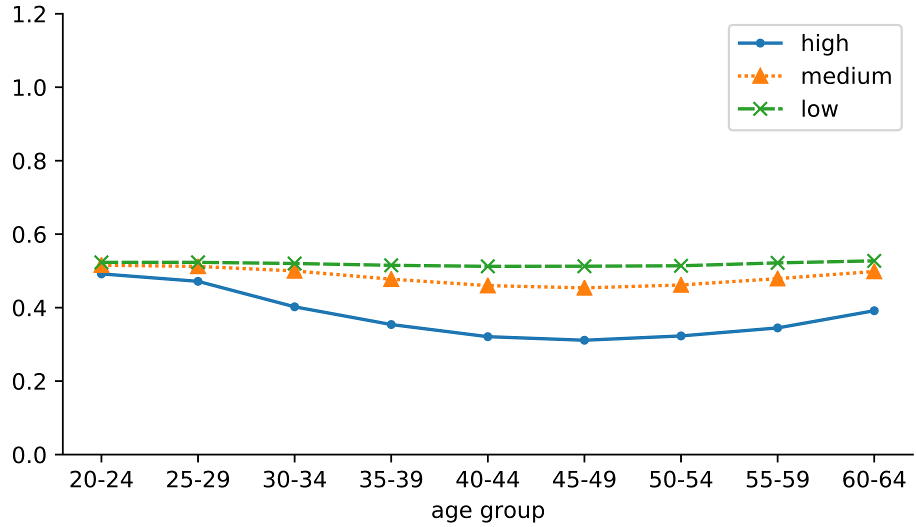


Figure 4: Average effective UI replacement rate by age and education

Notes: Age profiles of average imputed effective UI replacement rate by educational attainment (averages of monthly data over time).
Source: CPS basic monthly data and ETA UI policy statistics.

affected, further lowering average replacement rates over the life cycle. In sum, there are substantial differences with respect to education between the life-cycle profiles of effective replacement rates. Given th simple structure of the system, the rich heterogeneity in effective replacement rates is quite remarkable and clearly designate such systems as a candidate class for policy analysis.

As shown, the forces determining the household response to UI policy vary systematically with age and with productivity. Moreover, existing U.S. policy already differentiates along these dimensions. The obvious next questions are (i) whether this differential treatment is beneficial in terms of welfare and (ii) which policies are optimal. These question is addressed in the next section.

4 Laboratory economy

The model is a lifecycle model with endogenous human capital accumulation, idiosyncratic labor risk and idiosyncratic labor productivity. The model is partial in the sense that it abstracts from the productive sector. As a consequence, there are no general equilibrium feedback effects of e.g. aggregate labor supply on wages or asset holdings on interest rates.

4.1 Model

Framework There is a continuum of workers with total mass normalized to 1. Before entering the model, each worker draws a discrete type $k \in K$ that captures permanent differences in ability between workers. The type probabilities, and therefore the shares of workers of a given group in the total population, are constant over time. Workers live for a total of $\bar{n}_w + \bar{n}_r$ periods, the first $\bar{n}_w$ of which they are active in the labor market and the last $\bar{n}_r$ of which they are retired. All workers enter the model without having a job.

Preferences Workers receive utility from consumption c and leisure l in every period of their lives and maximize expected discounted lifetime utility. The flow utility from consumption and leisure utility captured by an additively separable CRRA specification

$$U(c,l) = \frac{c^{1-\sigma^c}}{1-\sigma^c} + \alpha \frac{l^{1-\sigma^l} - 1}{1-\sigma^l} \tag{1}$$

For ease of notation, let $u(c)$ denote the utility component from consumption and $\psi(l)$ denote the utility component from leisure. Note that the utility from consuming 1 unit of leisure is normalized to zero. Preferences are homogenous, i.e. all workers have the same utility specification and a common discount factor β.

Financial markets When workers enter the model, they start with initial assets $a_{k,0}$. Financial markets are incomplete, in that the only available saving device is a riskless bond that pays a constant interest rate r satisfying $\beta = \frac{1}{1+r}$. Workers are allowed to borrow up to the borrowing limit $\underline{a}$[3].

Labor markets Labor markets are fragmented: employers can observe worker types and workers of a given type can only work in their respective labor market. As a consequence, job separation rates and job finding rates are independent between markets. Within each labor market, the setup is identical. The timing in each labor market is characterised by two phases, search phase and consumption phase.

[3] I assume a fixed and exogenous borrowing limit that is identical across worker types. While it is perceivable that borrowing limits are type-dependent in practice (e.g. when degrees are interpreted by financial markets as credible signals for higher expected future wages), the role of the borrowing constraint is not the focus of this analysis, and examining the implications of relaxing this assumption is reserved for future research.

In the search phase, workers that do not have a job can find employment by investing time in search. All workers are endowed with one unit of time. The relationship between search effort and the job finding probability is captured by the search technology $\zeta_k : [0,1] \to [0,1]$. Search technology is assumed to be cubic and truncated between zero and one: $\zeta_k(s) = \max\{0, \min\{1, \theta_k s + \mu_k\}\}$. The parameters of the search technology function are type-dependent, i.e. I allow for differences in the efficacy of search for different types. Successful job search leads to a job in the same period. Time not invested in search is enjoyed as leisure. Workers that are already matched to a job do not search and consume their entire time endowment as leisure, which, given the normalization of the leisure utility function, yields leisure utility of zero.

In the second phase, all employed workers receive pre-tax wages $\bar{\omega}h$, where $\bar{\omega}$ is the average wage level and h is the worker's level of accumulated human capital. In every period of employment, workers face the risk of becoming unemployed with exogenous probability $\delta_{k,n}$. Unemployed workers receive UI benefits b. All workers choose how much out of their available resources to consume and how much to save.

Human capital accumulation Next to the permanent ability of a worker, human capital is modelled as experience in the labor market. Upon entering the model, workers start with initial human capital level $h_{k,0}$. The human capital production technology is captured by a standard learning-by-doing (LBD) specification

$$h'_k(h, e) = \mathbb{1}_{\{e=1\}} \alpha_k h^{\phi_k} + (1 - \delta_k^h) h \tag{2}$$

where e is an indicator of whether the worker is employed, α_k captures the worker' type-specific learning ability, ϕ_k captures the type-specific curvature of new human capital with respect to current human capital, and δ_k^h is the type-specific human capital depreciation rate. LBD is one of two main specifications for human capital production in the literature. The alternative is dedicated skill investment in the tradition on Ben-Porath (1967) (BP). Both specifications have in common that workers with low current human capital and workers with highly productive human capital technologies have the strongest incentives to invest in human capital. Under BP, unemployed workers face the trade-off between investing in (or maintaining) human capital, searching for employment, and leisure. Consequently, The results should not depend on the specification of the human capital technology, at least qualitatively. Solving the model under BP is much more involved than under LBD, which is why the latter is chosen as technology.

Government policy The economy features three government programs: unemployment insurance, social security (pensions) and a general tax and transfer system. The UI system is financed by a proportional tax on labor income, τ^{UI}, and pays out benefits b to unemployed workers. The social security program is also financed by a proportional labor income tax, τ^{SS}, and pays out pension benefits π to retired worker. Pension benefits do not depend on type, age, assets, human capital, or earnings history. Finally, the government collects a general income tax, τ^{I}, on labor and capital income to finance lumpsum transfers T. Lumpsum transfers are paid to all workers in all periods and all states.

This paper focuses on the UI program. The social security program and the general tax and transfer system are included to insure that the model replicates the U.S. economy reasonably well. In essence, the social security program in the model ensures that the level of private savings for retirement is realistic and the general tax and transfers system aims at replicating redistribution across types that is prevalent in the U.S. economy.

Household problem At the core of the model is the worker optimization problem. There are two sequential decisions to take in every period, following the two phases in the labor market. In the first phase, workers without a job decide how much time to invest in job search and how much to enjoy leisure. In the second phase, all workers decide how much to consume out of their available resources and how much to save.

Given the separability of the flow utility, the normalization of the leisure utility function and the assumptions on labor supply and leisure consumption, the problem can be captured by three states through which the workers transition: *employed*, *unemployed*, and *searching*. The worker maximization problem can then be represented by a set of three value functions for each type k, corresponding to the three states a worker can be in within a given period. Denote by $c_k^e(n, h, a, a')$ and $c_k^u(n, h, a, a')$ the consumption levels of an employed worker and an unemployed worker with age n, human capital h, current assets a, and next periods assets a', respectively. Moreover, denote by $V_k^e(n, h, a)$ the expected present value of utility over the remaining lifecycle for an employed worker of type k, of age n, with human capital level h, and asset holdings a, assuming the worker behaves optimally in all subsequent periods. Denote by $V_k^u(n,h,a)$ and $V_k^s(n,h,a)$ the same quantity for unemployed workers and searching workers, respectively. The value of being employed is then given by the sum of utility from consumption in the current period and expected discounted continuation value of either directly transitioning to *employed* or being separated from the job and transitioning to *searching*, given that assets are chosen optimally:

$$V_k^e(n,h,a) = \max_{a' \geq \underline{a}} u(c_k^e(n,h,a,a')) + \beta \Big[(1-\delta_{k,n}) V_k^e(n+1, h'(h,1), a') + \delta_{k,n} V_k^s(n+1, h'(h,1), a') \Big] \tag{3}$$

The value of being in the *searching* state is given by the sum of leisure utility and the expected utility from either being *employed* or *unemployed* in the same period, depending on whether the job search was successful or not, given that search effort is chosen optimally:

$$V_k^s(n,h,a) = \max_{s \in [0,1]} \psi(1-s) + \zeta_k(s) V_k^e(n,h,a) + [1-\zeta_k(s)] V_k^u(n,h,a) \tag{4}$$

The value of being in the *unemployed* state is given by

$$V_k^u(n,h,a) = \max_{a' \geq \underline{a}} u(c_k^u(n,h,a,a')) + \beta V_k^s(n+1, h'(h,0), a') \tag{5}$$

which is the sum of consumption under unemployment and the expected discounted value from transitioning to *searching*, again given that assets are chosen optimally.

The consumption levels in the states of the consumption phase can be obtained from the budget constraint: For employed workers, we have

$$c_k^e(n,h,a,a') = (1-\tau^{UI}-\tau^{SS}-\tau^I)\bar{\omega}h + [1+(1-\tau^I)r]a + T - a' \tag{6}$$

For unemployed workers, the budget constraint implies that

$$c_k^u(n,h,a,a') = b_k(n,h) + [1+(1-\tau^I)r]a + T - a' \tag{7}$$

where $b_k(n,h)$ is the UI benefit function imposed by the policymaker.

Retired agents do not participate in the labor market anymore, hence only the consumption phase remains, where workers decide how much out of retirement pension income and accumulated capital they consume. In the absence of survival risk or any other risk during retirement, retired workers perfectly smooth consumption over the entire retirement period. In other words, they consume their retirement income plus the annuity value of their savings, $c^r(a) = \pi + T + \frac{(1-\tau^I)r[1+(1-\tau^I)r]^{\bar{n}_r}}{[1+(1-\tau^I)r]^{\bar{n}_r}-1}a$, and enjoy 1 unit of leisure in every period. Consumption during retirement thus only depends on the level of transfers and the asset level upon retirement, but neither on the workers acquired human capital nor on the state in the first period of retirement (i.e. the state to which the worker transitions from the last period of the working age). The value of retiring with asset level a for a worker of is then given by

$$V_k^e(\bar{n}_w+1, h, a) = V_k^u(\bar{n}_w+1, h, a) = \frac{1-\beta^{\bar{n}_r}}{1-\beta}U(c^r(a), 1) = \frac{1-\beta^{\bar{n}_r}}{1-\beta}u(c^r(a)) \quad \forall k \in K \quad (8)$$

All value functions can be solved for by backwards induction. Making extensive use of envelope conditions on optimal choices of consumption and search effort yields a set of three recursive first order conditions. Together with the terminal condition $c_k(\bar{n}_w + \bar{n}_r + 1, h, a) = 0 \ \forall \ k \in K$, value functions at model entry can be obtained iteratively. Recall that workers enter the model without a job (i.e. in the *searching* state) and with initial human capital $h_{k,0}$ and initial assets $a_{k,0}$. Thus, after the type of a worker has materialized, the expected discounted value of lifetime utility for that worker is given by $V_k^s(0, h_{0,k}, a_{0,k})$. Before drawing the type, a worker has expected discounted value of lifetime utility of

$$\sum_{k \in K} \chi_k V_k^s(0, h_{k,0}, a_{k,0}) \quad (9)$$

For further details on the solution algorithm, see Appendix B.

Government problem In this paper, the government problem consists of choosing the optimal UI system. For this purpose, the social security tax τ^{SS} and the general income tax τ^I are assumed to be exogenous to the government. The level of retirement pensions pi and lumpsum transfers T is then determined by budget balance. All three government programs are assumed to be self-financing, i.e. the government faces three budget constraints. I assume that the government budgets need to be balanced in aggregates only, i.e. I allow for transfers across types within a given program. This is a slight deviation from the strand of literature assuming actuarially fair policies (e.g. Hopenhayn and Nicolini, 1997, or Shimer and Werning, 2007, 2008). By allowing for transfers across types, the policies are only actuarially fair before the type of the agent is drawn. In other words, before entering the model, the worker expects zero net transfers in present value. Once the type is revealed, some workers are net payers and some workers are net receivers. The assumption is motivated by how UI systems are implemented in reality. While typically not the main objective of the system, most UI policies feature some degree of redistribution, through differential unemployment probabilities by types and often through caps on benefit amounts. For the assessment of the welfare implications of UI policy, it is therefore necessary to account for the distributional effects as well. Naturally, effects from more efficient search behavior and effects from redistribution blend in such a treatment.

The budget conditions are given by the following equations:

- Unemployment insurance:

$$\sum_{k\in K}\sum_{n=0}^{\bar{n}_w}\beta^n\int_{R^+} b_k(n,h)\chi_k^u(n,dh) = \sum_{k\in K}\sum_{n=0}^{\bar{n}_w}\beta^n\int_{R^+}\tau^{UI}\bar{\omega}h\chi_k^e(n,dh) \tag{10}$$

- Social security:

$$\sum_{k\in K}\sum_{n=\bar{n}_w+1}^{\bar{n}_w+\bar{n}_r}\beta^n\pi\chi_k = \sum_{k\in K}\sum_{n=0}^{\bar{n}_w}\beta^n\int_{R^+}\tau^{SS}\bar{\omega}h\chi_k^e(n,dh) \tag{11}$$

- General tax and transfer system:

$$\sum_{k\in K}\sum_{n=0}^{\bar{n}_w+\bar{n}_r}\beta^n T\chi_k = \sum_{k\in K}\left(\sum_{n=0}^{\bar{n}_w}\beta^n\int_{R^+}\tau^I\bar{\omega}h\chi_k^e(n,dh) + \sum_{n=0}^{\bar{n}_w+\bar{n}_r}\beta^n\int_{R^+}\tau^I ra\chi_k(n,da)\right) \tag{12}$$

where χ_k are the type weights, $\chi_k^e(n,dh)$ and $\chi_k^u(n,dh)$ are the measures of workers of age n with human capital level h that are employed and unemployed, respectively, and $\chi_k(n,da)$ is the measure of all workers of age n and with assets a.

Constraints (11) and (12) mechanically adjust transfers to account for spillover effects of changes in labor supply induced by UI policy. Constraint (10) directly enters the government optimization problem.

UI benefits are functions of a workers type, age, and experience, $b_k(n,h)$ for $k\in K$. In the most general formulation analyzed in this paper, benefits are a function of pre-unemployment wages, a replacement rate that may depend on age and type, a general benefit floor and a general benefit cap:

$$b_k(n,h) = \min\{b_{max}, \max\{b_{min}\rho_{k,n}\bar{\omega}h*\}\} \tag{13}$$

where $h*$ denotes the pre-unemployment level of human capital. To disentangle the effects of individual components of this benefit function, I additionally consider the following subsets of policy instruments:

- common and constant replacement rate: $b_k(n,h) = \bar{\rho}\bar{\omega}h* \;\forall\, k \in K$
- age-dependent replacement rates: $b_k(n,h) = \rho_n\bar{\omega}h* \;\forall\, k \in K$
- age-and-type-dependent replacement rates: $b_k(n,h) = \rho_{k,n}\bar{\omega}h*$
- common and constant rate with cap and floor for total UI benefits: $b_k(n,h) = \max\{b_{min}, \min\{\bar{\rho}\bar{\omega}h*, b_{max}\}\}$

Formally, the government maximizes expected ex-ante present value of utility at entry (9) by setting the parameters of the benefit function $b_k(n,h)$ subject to the budget constraints (10)–(12).

4.2 Calibration and model fit

The model is calibrated to male individuals in the U.S. and parameters are obtained by matching selected model moments to their empirical counterparts.

Timing conventions One model period corresponds to one quarter and workers are assumed to enter the model at age 20. Workers are active in the labor market for 45 years (corresponding to $\bar{n}_w = 180$ periods), then retire deterministically at age 65, are retired for 20 more years (corresponding to $\bar{n}_r = 80$ periods) and exit the model deterministically at age 85.

Wages Wages are calibrated using CPS ASEC data on male workers aged 20 to 64 between 1990 and 2010. In the model, wages depend not on age, but on accumulated human capital, which in turn depends on a worker's employment history. The parameters of the human capital production functions, $\{\alpha_k, \gamma_k, \delta_k^h\}_{k\in K}$, are calibrated such that average wages in the laboratory economy match empirical wage profiles. The calibration is conducted in two steps.

First, empirical profiles of relative wages by age and type are obtained by regressing the log of deflated hourly wages on a full set of yearly age dummies, controlling for demographic factors such as race and marital status. The yearly age coefficients are then exponentiated to obtain relative wage levels by age and type. Relative wages are normalized such that the average relative wage at age 20 is equal to one. Finally, the moment conditions for the calibration are constructed by averaging over eight age brackets[4]. In the second step, the human capital technology for each type is calibrated such that simulated average wages match the estimated empirical targets by minimizing the distance between model moments and empirical targets.

Separation probabilities Separation rates are directly calibrated to observed separation probabilities. As mentioned in section 3, the CPS contains quarter-to-quarter changes in labor force status for about one quarter of the sample. I use these observations to compute average 3-month transition probabilities from employed to unemployed. For this, I first estimate a probit regression for the transition probability, controlling for age, education, race, marital status, and time effects. I then predict individual transition probabilities using the estimated model. The predicted transition probabilities are then used to compute average predicted transition probabilities by age group and education group (see figure A.1a and Appendix A.1 for more details). To obtain separation probabilities for all model ages, I construct a spline function through these averages. The knots of the spline correspond to the average age in the respective age group.

Preferences Risk aversion parameters for consumption and leisure are set to $\sigma^c = \sigma^l = 2.0$. This is within the range of parametrizations in the literature for specifications with separable consumption and leisure utility (see e.g. Guvenen, Kuruscu, and Ozkan (2013), Heathcote, Storesletten, and Violante (2017)). The discount factor is set to $\beta = 0.99$ which matches annual interest rates of approximately 4 percent.

[4] 21-24 years and seven brackets of five years each, ranging from 25 to 59.

Search technology As search effort is not observed in the data used for calibration, the parameters of the search technology are calibrated indirectly by matching unemployment rates by age and type. With separation rates set to empirical rates, unemployment rates in the model determined by job finding rates only. Note that preferences on leisure and search technology are not individually identified through job finding rates. After choosing a value for the preference parameter σ^l, the parameters of the search technology are selected by matching empirical unemployment rates. I allow for the search technology to depend on type. The calibrated values for the slope parameter $\{\theta_k\}_{k\in K}$ are $\{0.96, 0.98, 1.04\}$ for low, medium, and high productivity workers, respectively. The calibrated values for the intercept parameter $\{\mu_k\}_{k\in K}$ are $\{0.18, 0.16, 0.14\}$. The fit of simulated unemployment rates to calibration targets is depicted in panels (d) to (f) of figure 5. The close fit of model output and observed data supports the assumptions made above.

Borrowing limit The borrowing limit is taken from Michelacci and Ruffo (2015), where it is calibrated to the 2007 Survey of Consumer Finances (SCF). The calibration target is the fifth percentile of the net worth distribution of workers under 35, divided by average quarterly total income, which amounts to -0.61 in the data. The constraint is thus set to -0.61 times the mean quarterly total income in the economy, which corresponds to $\underline{a} = -1.12$ in the base calibration.

Policy Parameters Government policy consists of the UI benefits function, pension benefits, lumpsum transfers, and the respective tax rates. In the base calibration, the benefit function $b_k(n, h)$ is given by a common and constant UI replacement rate on pre-unemployment earnings which is set to $\bar{\rho} = 0.5$. This is well in line with the empirical findings in section 3 and comparable studies in the literature (see e.g. Chetty, 2008). The UI income tax rate is chosen endogenously to keep the government budget condition (10) balanced. In equilibrium, the base calibration requires the tax rates to be $\tau^{UI} = 0.014$.

The labor income tax financing the social security system is set to $\tau^{SS} = 0.05$. The US Social Security Administration (SSA) reports the tax rates for employers for the calibration period ranging between 5.015% and 5.3% (**SSA2022**). Retirement pensions are determined trough budget constraint (11) and in equilibrium is set to $\pi = 0.67$. This amounts to a ratio of retirement pensions over mean quarterly labor income of roughly 0.4, which is well in line with the empirical moments reported by OECD (2007).

Finally, the general income tax rate is set to $\tau^I = 0.15$. The congressional budget office reports average income taxes to range between 7.2% and 11.8% over the calibration period with an average of 9.3% (Congressional Budget Office, 2020). The corresponding level of equilibrium lumpsum transfers implied by budget condition (12) is $T = 0.20$. The complete calibration is summarized in table C.1 in the Appendix.

Fit to the data Figure 5 depicts the model fit for key variables by worker type. Panel 5a shows simulated relative wages (normalized to the average wage at model entry) against the empirical profiles of wages by type relative to average wages at age 20.[5] The model matches the empirical profiles closely, both in terms of shape and level. The model fails to replicate the decrease in empirical wage curves for workers close to retirement.

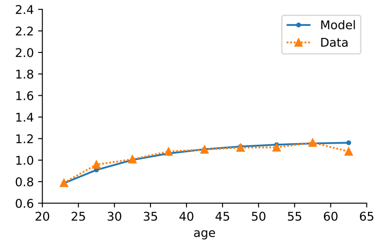
Panel 5b shows simulated unemployment rates versus their empirical counterpart. The empirical targets correspond to the unemployment probabilities presented in section 4.1. The simulated unemployment rates match the data very well. Since separation rates are matched exactly, unemployment probabilities are pinned down by the endogenous job finding rates. These are in turn determined by the combination of leisure utility and search technology. The good fit between simulated and empirical unemployment probabilities thus supports the assumptions made for leisure utility (preference homogeneity) and search technology (cubic technology).

Panel 5c shows simulated assets-over-quarterly-income ratios versus their empirical counterpart. Note that assets are not targeted in the calibration. Overall, the model generates lifecycle profiles of relative asset holdings that fit the empirical data remarkably well. The overall good fit of levels and profiles indicates that the model realistically replicates ability to self-insure by age and productivity.

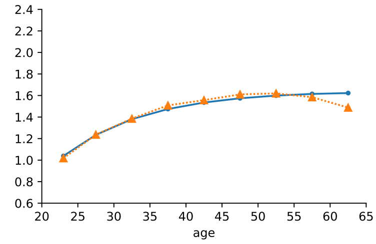
The model, however, underestimates asset holdings of young agents for all education groups. The simulated relative asset holdings of medium and, in particular, high types are lower than in the data. The latter deviation results in less variation in the ability to self-insure in the model than in the data. The differences to the data thus indicate that,

[5]For the construction of the empirical wage profiles, see section 4.1.

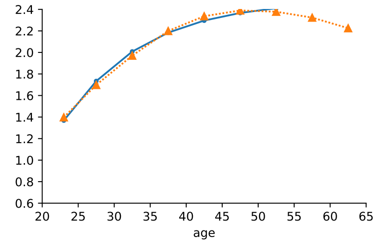
(a) wages



(i) low

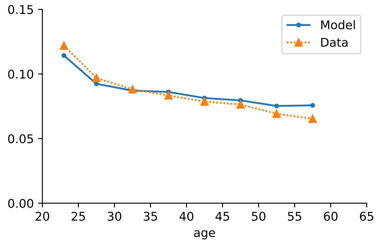


(ii) medium

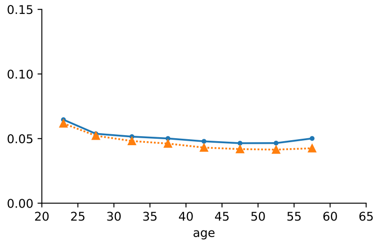


(iii) high

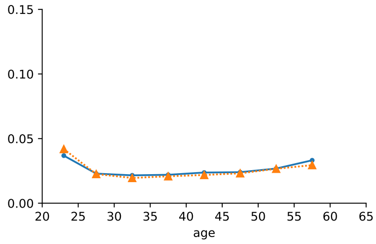
(b) unemployment rates



(i) low

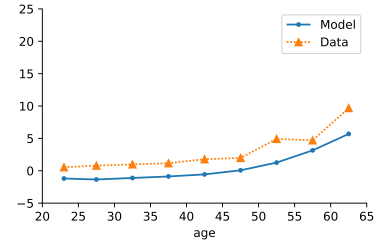


(ii) medium

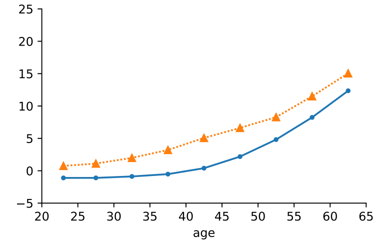


(iii) high

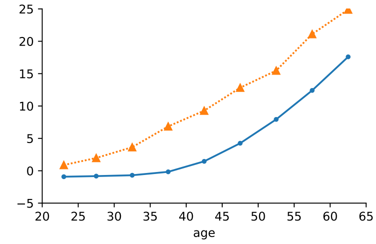
(c) assets over income



(i) low



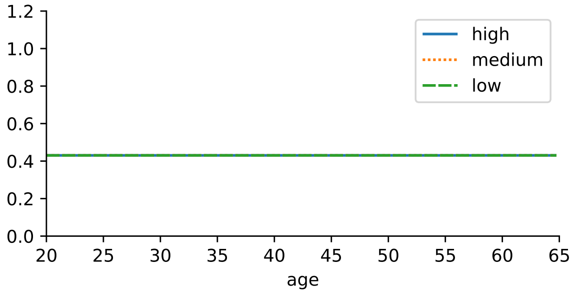
(ii) medium



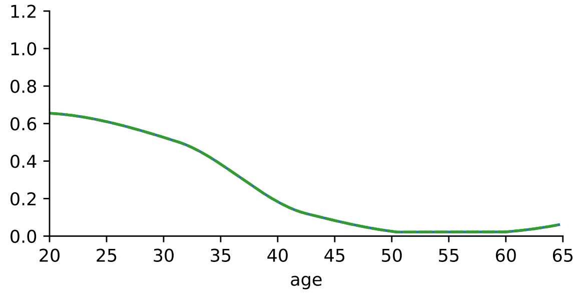
(iii) high

Figure 5: Fit of model outputs with observed data.

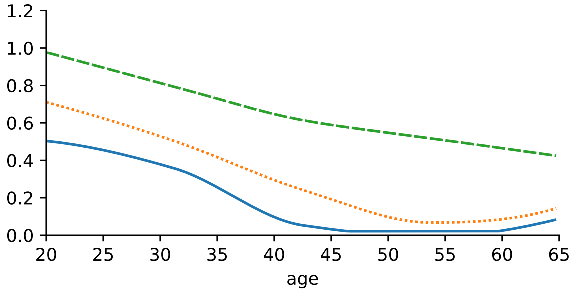
Notes: Panels (a) (i) to (a) (iii) depict simulated wages vs. empirical targets. Panels (b) (i) to (b) (iii) depict simulated unemployment rates vs. empirical targets. Panels (c) (i) to (c) (iii) depict simulated assets-over-quarterly-income ratios vs. empirical counterpart.



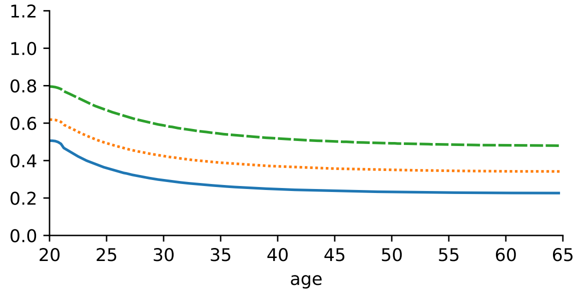
(a) Constant rate



(b) Age-dependent



(c) Age-and-type dependent



(d) Rate, floor and cap

Figure 6: Optimal policies: Effective replacement rates

if anything, variation in optimal replacement rates should be larger than predicted by the model.

5 Results

5.1 Policy experiments

I now consider the policy functions presented in section 4 and compute optimal parameters.[6] Note that this is a theoretical exercise with the purpose of quantifying the potential welfare gains from different policy instruments. Implementing a policy that explicitly conditions on age in a real life setting is, although age qualifies as observable and immutable indicator, at least controversial. Conditioning on idiosyncratic productivity directly is not feasible and implementing a policy that explicitly conditions on some observable proxy for productivity is likely to be practically impossible. Contrasting to this, the final class of instruments - rate, floor, and cap - does not feature any conditionality. It is simple and robust, and, as the basic features are already in place in the U.S., implementation would not require major policy reforms.

Figure 6 depicts the resulting life-cycle profiles of effective replacement rates. For the

[6]For more information on the optimization routine, see Appendix D.

scenarios *constant rate*, *age-dependent*, and *age-and-type-dependent*, replacement rates are directly set by the policymaker. In the *rate, floor, cap* scenario, effective replacement rates result from binding lower and upper bounds on benefits.

The optimal age-dependent policy exhibits the key features Michelacci and Ruffo (2015) found in their analysis on average workers: high replacement rates for young workers and string decline over the life cycle. Contrasting to the former result, optimal replacement rates do not drop to (close to) zero here. This is driven by the presence of low productivity workers. As they generally accumulate less capital than the average worker, removing public insurance against income loss would hurt them substantially. This becomes evident in the profiles of optimal age-and-type-dependent replacement rates (figure 6b). The falling life-cycle profile prevails, yet optimal replacement rates are higher throughout the life the lower the worker's productivity. This is in part driven by providing more insurance to those who value it more highly and in part by an increase in redistribution across types.

As we have already seen in section 3, the simple structure consisting of a fixed and common replacement rate, a benefit floor and a benefit cap can nonetheless generate rich heterogeneity in effective replacement rates w.r.t. age and type (see figure 6c). With parameters chosen optimally, this policy generates life cycle profiles that features remarkable qualitative similarities to the profiles generated by age-and-type-dependent policies: Higher replacement rates for the low types with a moderate decrease over the life cycle and lower replacement rates with a more pronounced decrease over the life cycle for high types. What is noticeable about this observation is that these patterns arise from a much smaller set of parameters and do not involve any conditionality.

5.2 Welfare analysis

To quantify the effects of the presented policies, I now turn to a simple welfare analysis using consumption equivalents. To construct consumption equivalents in an economy with heterogeneous workers, I fist compute consumption equivalents for all types separately and then calculate averages, weighted by population shares. The type-specific equivalents measure how consumption in the baseline setup would have to change - proportionally by the same factor in all periods and states - in order to make the worker at entry as well

Policy	Consumption equivalent low	medium	high	average
Age-and-type dependent	0.83	0.21	0.27	0.31
Age-dependent	0.16	0.25	0.23	0.23
Rate, floor, cap	0.53	0.13	0.11	0.18
Common and constant rate	0.02	0.04	-0.02	0.02

Table 1: Consumption equivalents of optimal implementations of policy instruments

Notes: Consumption equivalents are calculated using equation B.17. The reference scenario for all equivalents is the *baseline* calibration. For details on the computation of consumption equivalents, see Appendix B.2 Average consumption equivalents are obtained as weighted average over types.

off as under the alternative setup, while keeping all other quantities constant (including utility from leisure). The average measure cannot be interpreted in the same way, yet is still indicative of the relative size of the welfare effects of the proposed policies.

Table 1 summarizes the results of the welfare comparison. First, note that the consumption equivalents of the optimal common and constant replacement rate are small. This is in line with the existing results that the U.S. UI system is, on average, close to optimal.

The average consumption equivalent corresponding to optimally setting age-dependent replacement rates is 0.23 percentage points. These effects are smaller than the welfare effects of age-dependent replacement rates found in Michelacci and Ruffo (2015), which amount to 0.8 percentage points. Additionally conditioning on worker types increases welfare gains to 0.31 percentage points of consumption in all states and periods, or by about 35% compared to age-dependent rates. The welfare gains from imposing an optimal combination of common and constant replacement rate, benefit floor and benefit cap are equal to an increase in consumption of 0.18 percentage points, or about 80% of the gains from conditioning the replacement rate on age only and about 60% of the gains from conditioning the replacement rate on both age and type.

Part of the increase in consumption equivalents from differentiating by type (explicitly or implicitly) certainly stems from an increase in redistribution across types induced by these policies. However, not that all types are better off under any of the age-dependent, age-and-type-dependent, or rate-cap-and-floor policies. This indicates that, while redistribution is at play, a significant share of the welfare improvement is due to UI benefits that better acconut for the individual circumstances of the workers.

6 Conclusion

Differences in idiosyncratic productivity, translating into differences in labor market risks and opportunities over the life cycle, generate rich heterogeneity in the decision context in which the labor supply choice is taken. Using a life cycle model with permanent productivity types and endogenous human capital accumulation, I find that UI policies that account for these differences can generate sizeable welfare gains.

I replicate the finding of Michelacci and Ruffo (2015) that conditioning UI policy on age can generate sizeable welfare gains and that optimal replacement rates fall with age. In my calibration, implementing optimal age-dependent replacement rates is equivalent to an increase of consumption of 0.5 percentage points in all states and periods. Moreover, optimally conditioning UI replacement rates on age and type generates welfare gains of 0.74 percentage points of consumption. Two thirds of these gains, or about 0.5 percentage points of consumption, come from inducing more efficient search behavior and about one third stems from an increase in redistribution across types relative to baseline. One key addition to the results of Michelacci and Ruffo (2015) is that dropping replacement rates to (close to) zero for older workers could potentially hurt low productivity workers.

While these are theoretical considerations, as a real life implementation of policies explicitly conditioning on age and idiosyncratic productivity are difficult, if not impossible, simple and robustly implementable policies exist and can generate a substantial share of the welfare gains of these conditional policies. The current U.S. UI system proves to be one such policy, though the current parameterization leaves potential for improvement. Increasing the UI replacement rate to about 0.9 and at the same time setting the benefit floor and cap to approx 70 percent and 80 percent of the aggregate wage level, respectively, is equivalent to raising consumption in all states and periods by about 0.5 percent. This amounts to the entire welfare gains from age-dependent replacement rates and to about two thirds of the gains from a fully age-and-type-dependent policy.

The above focus on UI policy alone also represents one of the major limitations of the paper. As a range of studies have shown that extending the policies to include the financing side of the policy can vastly increase the potential welfare gains (see e.g. Huggett and Parra, 2010; Michelacci and Ruffo, 2015). A natural extension of this work is thus to include tax policies in the analysis.

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A Additional details on the empricial analyses

A.1 Further details on estimation procedures

Estimation of labor market statistics An individual's labor force status is reported as a categorical variable in the CPS. For my analysis, I only differentiate between three categories: *employed* (combining "employed - at work" and "employed - absent"), *unemployed* (combining "unemployed - looking" and "unemployed - on layoff"), and *not in labor force* (combining "retired", "disabled", "unavailable", and "other").

To predict individual unemployment / transition probabilities, I estimate probit models with the interaction of age group and education group as covariate of interest, controlling for time and state fixed effects, marital status and race. The estimated models are then used to predict average conditional effects by age group and education group.

Imputation of unemployment benefits For the imputation of individual level earnings, I run a conventional wage regression for each year and for each state using wage information from the CPS ASEC. The dependent variable is the log of reported *"usual weekly earnings before deductions"*, the independent variables are a quadratic polynomial of age, dummy variables for white and black individuals, a dummy variable for married individuals, as well as four dummies for educational attainment (*"Less than a High School Diploma"*, *"High School graduates, no College"*, *"Some College or Associate Degree"*, and *"Bachelor's Degree and higher"*). Using the estimated coefficients, individual pre-unemployment earnings are then imputed for all unemployed male individuals aged between 16 and 64 years in the respective CPS basic monthly surveys.

In the second step, unemployment benefits are imputed using the approach of Cullen and Gruber (2000). The ETA publishes semiannual summaries of state UI laws for all U.S. states[7]. These summaries include, among other statistics, the parameters for the computation of weekly benefit amounts as well as upper and lower bounds for weekly benefits. In the current setup, I simulate base benefits and, for the states in which they apply, additional benefits from dependent allowances. For the number of dependents, I currently only use information on unemployed / non-working spouses, as information of dependent

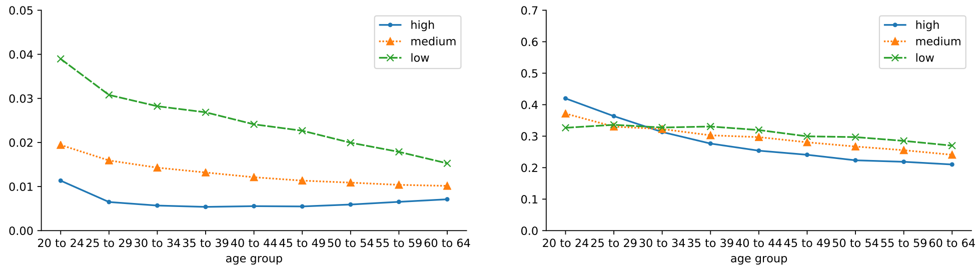
[7] Employment and Training Administation (1989–2020)

children is not available for all years in the sample in the CPS. In most U.S. states, weekly benefit amounts are a function of wages in a base period prior to unemployment (usually the five quarters prior to the unemployment spell). A precise calculation of potential UI benefits would thus require knowledge about the recent earning history of the individual. As the CPS basic monthly survey features a very limited panel dimension, base period earnings cannot be observed directly and need to be approximated. I use multiples of imputed pre-unemployment weekly earnings as proxy for base period earnings. Moreover, I currently do not simulate qualification requirements for unemployment benefits that exist in some states. Both simplifying assumptions are in line with the literature (see e.g. Michelacci and Ruffo (2015) and Chetty (2008)). The validity of this approach has also been demonstrated in the original study by Cullen and Gruber (2000): approximating base period earnings with earnings in the output quarter yields a correlation between potential benefits of 0.90, and additionally abstracting from qualification rules lowers the correlation between approximated and actual potential benefits to 0.88.

A.2 Further empirical results

Labor market transition probabilities The structure of the CPS allows for a decomposition of unemployment probabilities into the probability to transition from employment to unemployment and vice versa. I estimate both probabilities with the same procedure as for the estimation of unemployment probabilities (see section 3 for results and Appendix A.1 for details on the estimation procedure). Figure A.1 depicts the age-profiles of transition probabilities by education.

As can be seen in figure A.1a, the employed to unemployed transition probabilities exhibit a similar pattern as unemployment rates: a strict ordering by education for all age groups and a general decrease over the life-cycle. Average unemployed to employed transition probabilities, however, present a different picture (see figure A.1a). While there is a general common downward trend over the life-cycle, there is no strict ordering by education across age groups: the transition probability for college graduates is highest for young workers and lowest for older workers, relative to the other groups.

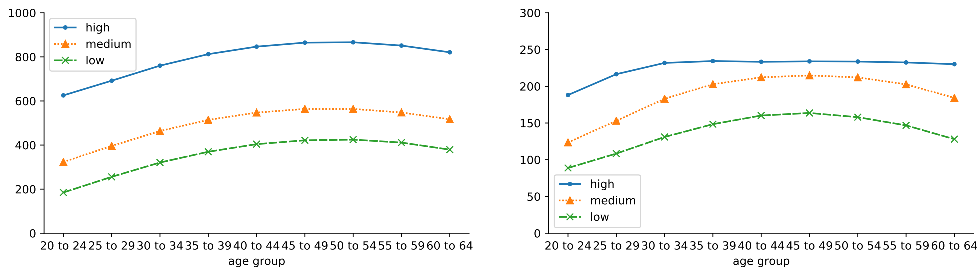


(a) employed-to-unemployed (b) unemployed-to-employed

Figure A.1: 1-month transition probabilities

Notes: Estimated average transition probability from *employed* to *unemployed* (left panel) and from *unemployed* to *employed* (right panel) by age group and education group (male CPS sample, 1989–2018).
Source: CPS basic monthly data.

Earnings and benefits statistics Figure A.2 depicts life-cycle profiles of earnings and UI benefits by education group.



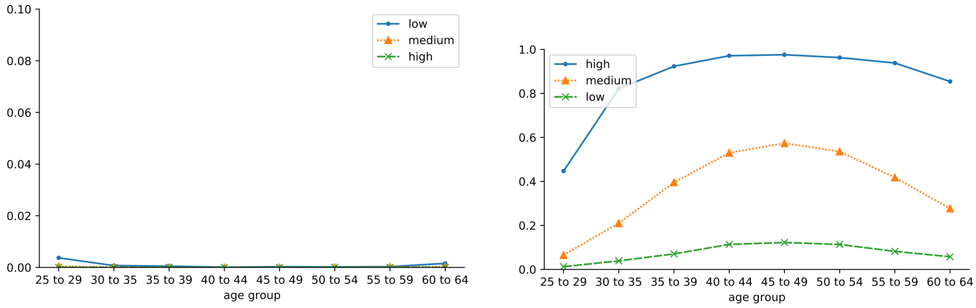
(a) imputed pre-unemployment earnings (b) imputed UI benefits

Figure A.2: Average income statistics by age and education

Notes: Age profiles of average imputed weekly pre-unemployment earnings (left), average imputed weekly UI benefits (right) (both in 1990 dollars).
Source: CPS basic monthly data and ETA UI policy statistics.

The flattening of the benefit profiles is driven by the benefit cap: higher average earnings imply that a larger fraction of workers are affected by the cap. The higher proportion of workers at the upper bound then translates into lower effective replacement rates.

The share of individuals affected by UI cap and floor is depicted in figure A.3a. As can be seen, the floor is largely ineffective: the share of individuals affected is virtually zero for all but low education workers at the beginning of their working life and close to retirement. As expected from the benefit profiles, the upper bound plays a significant role for many individuals, especially for high education workers. The share of recipients at the bound exhibits an inverse u-shape over the life cycle, following the shape of (pre-unemployment) earnings. For intermediate age groups, almost all high education recipients are at the bound. This is the main driver behind the heterogeneity in effective replacement rates discussed in section 3.



(a) benefit floor

(b) benefit cap

Figure A.3: Share of UI benefit recipients affected by bounds

Notes: Age profile of share of UI benefit recipients affected by benefit floor (left panel) and benefit cap (right panel) by education group (low: solid blue line; medium: dotted orange line; high: dashed green line). Benefits are imputed using methodology of Cullen and Gruber, 2000. Graphs show averages over the full CPS sample from 1989–2018.
Source: CPS basic monthly data, CPS ASEC data, and ETA UI statistics.

B Additional derivations

B.1 Solving the baseline economy

First-order conditions of the household problem The first order conditions for the consumption choices are obtained from the value functions in section 4. The following derivations focus on interior solutions, thus omitting the Kuhn-Tucker multipliers for the constraints on parameters. In case any of the constraints are binding, the solutions can be directly obtained from the constraints.

Let $a_k^e(n,h,a)$ and $a_k^u(n,h,a)$ be the asset choice that solves the maximization problem in a given period for employed workers and unemployed workers, respectively and let

$$
\begin{aligned}
c_{k,opt}^e(n,h,a) &= c_k^e(n,h,a,a_{k,opt}^e(n,h,a)) \\
c_{k,opt}^u(n,h,a) &= c_k^u(n,h,a,a_{k,opt}^u(n,h,a))
\end{aligned}
$$

denote the corresponding optimal consumption choices. For interior solutions, $a_{k,opt}^e(n,h,a)$ satisfies

$$
u'(c_k^e(n,h,a,a')) = \beta(1-\delta_{k,n})\frac{\partial V_k^e(n+1,h_k'(h,1),a')}{\partial a'} + \beta\delta_{k,n}\frac{\partial V_k^s(n+1,h_k'(h,1),a')}{\partial a'} \tag{B.1}
$$

We can eliminate the maximum operator in the value function by substituting the solution to the maximization problem. The value function is then given by

$$
\begin{aligned}
V_k^e(n,h,a) = u(c_k^e(n,h,a,a_{k,opt}^e(n,h,a))) \\
+ \beta(1-\delta_{k,n})V_k^e(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a)) \\
+ \beta\delta_{k,n}V_k^s(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a))
\end{aligned} \tag{B.2}
$$

Taking derivatives w.r.t. a yields

$$\begin{aligned}\frac{\partial V_k^e(n,h,a)}{\partial a} =& \frac{\partial c_k^e(n,h,a,a_{k,opt}^e(n,h,a))}{\partial a} u'(c_k^e(n,h,a,a_{k,opt}^e(n,h,a)) \\ &+ \frac{\partial c_k^e(n,h,a,a_{k,opt}^e(n,h,a))}{\partial a'} \frac{\partial a_{k,opt}^e(n,h,a)}{\partial a} u'(c_k^e(n,h,a,a_{k,opt}^e(n,h,a)) \\ &+ \beta(1-\delta_{k,n}) \frac{\partial a_{k,opt}^e(n,h,a)}{\partial a} \frac{\partial V_k^e(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a))}{\partial a'} \\ &+ \beta\delta_{k,n} \frac{\partial a_{k,opt}^e(n,h,a)}{\partial a} \frac{\partial V_k^s(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a))}{\partial a'} \\ =& [1+(1-\tau^I)r] u'(c_k^e(n,h,a,a_{k,opt}^e(n,h,a)) \\ &- \frac{\partial a_{k,opt}^e(n,h,a)}{\partial a} u'(c_k^e(n,h,a,a_{k,opt}^e(n,h,a)) \\ &+ \frac{\partial a_{k,opt}^e(n,h,a)}{\partial a} \beta(1-\delta_{k,n}) \frac{\partial V_k^e(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a))}{\partial a'} \\ &+ \frac{\partial a_{k,opt}^e(n,h,a)}{\partial a} \beta\delta_{k,n} \frac{\partial V_k^s(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a))}{\partial a'} \\ =& [1+(1-\tau^I)r] u'(c_{k,opt}^e(n,h,a))\end{aligned} \tag{B.3}$$

where the last step uses the envelope condition (B.1). Analogously, again making use of the respective envelope conditions on optimal asset policies, we obtain

$$\frac{\partial V_k^u(n,h,a)}{\partial a} = [1+(1-\tau^I)r] u'(c_{k,opt}^u(n,h,a)) \tag{B.4}$$

Now, let $s_{k,opt}^s(n,h,a)$ solve the maximization problem in equation (4). This implies that, for interior solutions, $s_{k,opt}^s(n,h,a)$ satisfies

$$\psi'(1-s_{k,opt}^s(n,h,a)) = \zeta_k'(s_{k,opt}^s(n,h,a))[V_k^e(n,h,a) - V_k^u(n,h,a)] \tag{B.5}$$

Again substituting the solution for the maximum operator, the value function for searching workers becomes

$$\begin{aligned}V_k^s(n,h,a) =& \psi(1-s_{k,opt}(n,h,a)) + \zeta_k(s_{k,opt}^s(n,h,a))V_k^e(n,h,a) \\ &+ [1-\zeta_k(s_{k,opt}^s(n,h,a))]V_k^u(n,h,a)\end{aligned} \tag{B.6}$$

Taking derivatives w.r.t. current asset holdings a and employing the envelope condition (B.5) yields

$$\frac{\partial V_k^s(n,h,a)}{\partial a} = \zeta_k(s_{k,opt}^s(n,h,a)) \frac{\partial V_k^e(n,h,a)}{\partial a} + [1-\zeta_k(s_{k,opt}^s(n,h,a))] \frac{\partial V_k^u(n,h,a)}{\partial a} \tag{B.7}$$

With the expressions for the derivatives of the value functions ((B.3), (B.4), and (B.7)), it is straightforward to compute the first order conditions for interior solutions to the consumption / savings choice. Imposing the optimality conditions defining $a^e_{k,opt}$, $a^u_{k,opt}$, and $s^s_{k,opt}$ for all periods, the first-order condition for employed workers becomes

$$
\begin{aligned}
u'(c^e_{k,opt}(n,h,a)) &= \beta\delta_{k,n}\frac{\partial V^e_k(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a))}{\partial a'} \\
&\quad + \beta(1-\delta_{k,n})\frac{\partial V^s_k(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a),1)}{\partial a'} \\
\Leftrightarrow u'(c^e_{k,opt}(n,h,a)) &= \beta[1+(1-\tau^I)r]\Big[(1-\delta_{k,n})u'(c^e_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a))) \\
&\quad + \delta_{k,n}\big[\zeta_k(s^s_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a),1))u'(c^e_{k,opt}(n+1, h'_k(h,1)), a^e_{k,opt}(n,h,a)) \\
&\quad + [1-\zeta_k(s^s_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a),1))]u'(c^u_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a),1))\big]\Big]
\end{aligned}
$$

With $u'(c) = c^{-\sigma}$ and $u'^{-1}(c) = c^{-\frac{1}{\sigma}}$, we then get

$$
\begin{aligned}
c^e_{k,opt}(n,h,a) &= [\beta[1+(1-\tau^I)r]]^{-\frac{1}{\sigma}}\Big[(1-\delta_{k,n})c^e_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a))^{-\sigma} \\
&\quad + \delta_{k,n}\big[\zeta_k(s^s_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a),1))c^e_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a))^{-\sigma} \\
&\quad + [1-\zeta_k(s^s_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a),1))]c^u_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a),1)^{-\sigma}\big]\Big]^{-\frac{1}{\sigma}}
\end{aligned} \tag{B.8}
$$

The first-order condition for consumption of unemployed workers is derived analogously. It is given by

$$
\begin{aligned}
c^u_{k,opt}(n,h,a) &= [\beta(1+(1-\tau^I)r)]^{-\frac{1}{\sigma}}\Big[\\
&\quad \zeta_k(s_{k,opt}(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a))c^e_{k,opt}(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a))^{-\sigma} \\
&\quad + [1-\zeta_k(s_{k,opt}(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a)))]c^u_{k,opt}(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a))^{-\sigma}\Big]^{-\frac{1}{\sigma}}
\end{aligned} \tag{B.9}
$$

Finally, solving the envelope condition (B.5) for search effort $s_{k,opt}$ yields the first-order condition

$$
s_{k,opt}(n,h,a) = 1 - \psi'^{-1}\Big(\zeta'_k(s_{k,opt}(n,h,a))\big[V^u_k(n,h,a) - V^e_k(n,h,a)\big]\Big) \tag{B.10}
$$

With linear search technology, $\zeta'_k(s_{k,opt}(n,h,a))$ is a constant and the FOC can easily be used to compute optimal search effort.

The household optimization problem can now easily be solved by backwards induction. As mentioned before, retired households optimally consume their retirement pension income plus the annuity of their asset holdings. Value functions, consumption/ saving policy functions and search effort policy functions for working age households can be obtained by iterating over the first-order conditions ((B.8)–(B.10)) for all working age periods.

Solving for equilibrium tax policies Once the policy functions have been derived, it is possible to check the government budget constraint by computing expected present values of net cost to the government at model entry. For this, denote the present value of net cost to the government of an employed worker of type k, age n, human capital level h, and asset holdings a by $C_k^e(n,h,a)$. Let $C_k^u(n,h,a)$ denote the same quantity for unemployed workers. Note that the government discounts flows using the pre-tax interest rate r. Given the optimal policies derived above, these present value cost functions can then be expressed recursively for all working age periods by

$$\begin{aligned} C_k^e(n,h,a) &= T - (\tau^I + \tau^{UI} + \tau^{SS})\bar{\omega}h - \tau^I ra \\ &+ \frac{1}{1+r}(1-\delta_{k,n})C_k^e(n+1, h_k'(h,1), a_{k,opt}^e(n,h,a)) \\ &+ \frac{1}{1+r}\delta_{k,n}\Big[\zeta_k(s_{k,opt}^s(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a))C_k^e(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a)) \\ &\quad + [1-\zeta_k(s_{k,opt}^s(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a)))]C_k^u(n+1,h_k'(h,1),a_{k,opt}^e(n,h,a))\Big] \end{aligned} \tag{B.11}$$

for employed workers. For unemployed workers, cost functions are given by

$$\begin{aligned} C_k^u(n,h,a) &= T + b_k(n,h) - \tau^I ra + \frac{1}{1+r}\Big[\\ &\zeta_k(s_{k,opt}^s(n+1,h_k'(h,0),a_{k,opt}^u(n,h,a)+1))C_k^e(n+1,h_k'(h,0),a_{k,opt}^u(n,h,a)) \\ &+ [1-\zeta_k(s_{k,opt}^s(n+1,h_k'(h,0),a_{k,opt}^u(n,h,a))]C_k^u(n+1,h_k'(h,0),a_{k,opt}^u(n,h,a))\Big] \end{aligned} \tag{B.12}$$

In retirement, workers of all types receive pension benefits π for all remaining periods of life in addition to the lumpsum transfers T that all agents receive in all periods. Retired workers only pay income tax on their asset income. Cost from pensions and lumpsum transfers are constant streams and can be summarized in net present value terms (discounted to the first period of retirement) by the discount factor β_c given by

$$\beta_c^r = \frac{(1+r)^{\bar{n}_r} - 1}{r(1+r)^{\bar{n}_r - 1}}$$

Revenues from taxing asset income represent interest payments on an amortized loan and can be summarized in net present value terms (again discounted to the first period of retirement) by the discount factor β_r^r given by

$$\beta_r^r = \frac{(1-\tau^I)[1+(1-\tau^I)r]^{\bar{n}_r} + (1+r)^{\bar{n}_r}(\tau^I[1+(1-\tau^I)r]^{\bar{n}_r} - 1)}{(1+r)^{\bar{n}_r - 1}([1+(1-\tau^I)r]^{\bar{n}_r} - 1)}$$

The present value of net cost to the government for retired workers, discounted to the first period of retirement, is then given by

$$C_k^e(\bar{n}_w+1, h, a) = C_k^u(\bar{n}_w+1, h, a) = \beta_c^r(\pi + T) + \beta_r^r a \tag{B.13}$$

With expressions ((B.11)–(B.13)), period zero cost functions for employed and unemployed workers can be obtained by backwards induction. The cost functions for workers at model entry, i.e. in the searching stage at period zero, are given by

$$C_k^s(0, h_0, a_0) = \zeta_k(s_{k,opt}(0, h_0, a_0))C_k^e(0, h_0, a_0) + [1 - \zeta_k(s_{k,opt}(0, h_0, a_0))]C_k^u(0, h_0, a_0) \tag{B.14}$$

The government budget is satisfied, if the expected cost at model entry (i.e. prior to drawing the type) is zero:

$$\sum_{k \in K} \chi_k C_k^s(0, h_0, a_0) = 0 \tag{B.15}$$

For a given UI policy choice, the model is solved by (i) guessing equilibrium parameters of the tax functions, (ii) deriving optimal policies and present value cost functions, (iii) checking the government budget constraint and, if necessary, adjusting the guess for the income tax parameters until a pre-specified tolerance for the budget condition is met.

B.2 Computing consumption equivalents

As mentioned before, consumption equivalents in this framework are defined as the percentage change in consumption in every state and period required to make workers as well off under the baseline economy as under an alternative calibration, *keeping leisure utility constant*. The exercise therefore consists in (i) isolating the utility from consumption only in the baseline scenario and (ii) computing the required proportional change in consumption to equate total utility in both scenarios.

To formalize the concept, consider a given set of policy functions for consumption and search effort. Recall that $V_k^e(n, h, a)$ denotes the present value of total utility for an employed worker of type k, age n, human capital level h, and asset holdings a given these policy functions. Denote by $U_k^e(n,h,a)$ and $L_k^e(n,h,a)$ the present values of consumption utility and leisure utility, respectively, for the same worker and the same set of policies. By definition, we have that $V_k^e(n,h,a) = U_k^e(n,h,a)+L_k^e(n,h,a)$. Analogously, let $U_k^u(n,h,a)$, $L_k^u(n,h,a)$, $U_k^s(n,h,a)$, and $L_k^s(n,h,a)$ be the present values of consumption utility and leisure utility for unemployed and searching workers. Now, consider workers that exerts the same search effort as before, but consumes θ times the consumption level of the above allocation in all states and periods. Denote the present value at entry of consumption utility for this worker by $\tilde{U}_k^s(\theta)$. Note that, by definition, $\tilde{U}_k^s(1) = U_k^s(0,h_0,a_0)$. Also note that, due to the CRRA functional form, the adjusted consumption utility in any period is given by $u(\theta c) = \frac{(\theta c)^{1-\sigma}}{1-\sigma} = \theta^{1-\sigma}\frac{c^{1-\sigma}}{1-\sigma} = \theta^{1-\sigma}u(c)$. Since all utility terms in the present value of consumption utility exhibit this property, the multiplier can be drawn out of the expectation, and we obtain $\tilde{U}_k^s(\theta) = \theta^{1-\sigma}\tilde{U}_k^s(1) = \theta^{1-\sigma}U_k^s(0,h_0,a_0)$.

Now, let $V_{k,base}^s(0,h_0,a_0)$, $U_{k,base}^s(0,h_0,a_0)$, $L_{k,base}^s(0,h_0,a_0)$, and $\tilde{U}_{k,base}^s(\theta)$ be the present values at entry of a searching worker of type k that has zero human capital and zero wealth for the quantities total utility, consumption utility, leisure utility, and adjusted consumption utility (given the optimal policies of the baseline scenario), respectively. Let $\tilde{V}_k^s(0,h_0,a_0)$ be NPV of total utility at entry of an alternative scenario. The multiplier θ for this alternative scenario is then defined by the condition

$$\tilde{V}_k^s(0,h_0,a_0) = \tilde{U}_{k,base}^s(\theta) + L_{k,base}^s(0,h_0,a_0) = \theta^{1-\sigma}U_{k,base}^s(0,h_0,a_0) + L_{k,base}^s(0,h_0,a_0) \tag{B.16}$$

Expressing the welfare gain of an alternative scenario relative to the baseline scenario as the difference in expected present value at entry, we obtain

$$\begin{aligned}\Delta W_k &= \tilde{V}_k^s(0,h_0,a_0) - V_{k,base}^s(0,h_0,a_0)\\ &= \theta^{1-\sigma}U_{k,base}^s(0,h_0,a_0) + L_{k,base}^s(0,h_0,a_0) - V_{k,base}^s(0,h_0,a_0)\\ &= \theta^{1-\sigma}U_{k,base}^s(0,h_0,a_0) - U_{k,base}^s(0,h_0,a_0)\\ &= (\theta^{1-\sigma}-1)U_{k,base}^s(0,h_0,a_0)\end{aligned}$$

Defining the consumption equivalent of a welfare gain as $CE(\Delta W_k) = \theta(\Delta W_k) - 1$, we then obtain

$$CE(\Delta W_k) = \left[\frac{\Delta W_k}{U_{k,base}^s(0,h_0,a_0)} + 1\right]^{\frac{1}{1-\sigma}} - 1 \tag{B.17}$$

Thus, the only quantities required to compute consumption equivalents are the difference in welfare between the alternative scenario and the baseline scenario and the present value at entry of consumption utility in the baseline scenario.

Solving for consumption utility in a base scenario To compute consumption utility in the base scenario, consider the set of optimal policies

$$\{\{c^e_{k,opt}(n,h,a), c^u_{k,opt}(n,h,a), s_{k,opt}(n,h,a)\}_{n=1}^{\bar{n}_w}\}_{k\in K} \tag{B.18}$$

Use consumption policies and the respective budget constraints to derive optimal savings policies

$$\{\{a^e_{k,opt}(n,h,a), a^u_{k,opt}(n,h,a)\}_{n=0}^{\bar{n}_w}\}_{k\in K} \tag{B.19}$$

With the complete set of optimal policies from the baseline scenario, the present value of consumption utility by state, type, age, human capital level, asset level, and unemployment duration can be expressed recursively by the following set of equations for employed workers

$$\begin{aligned} U^e_k(n,h,a) = u(c^e_{k,opt}(n,h,a)) & \\ & + \beta(1-\delta_{k,n})U^e_k(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a)) \\ & + \beta\delta_{k,n}\zeta_k(s_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a))) \\ & \quad * U^e_k(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a)) \\ & + \beta\delta_{k,n}[1-\zeta_k(s_{k,opt}(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a)))] \\ & \quad * U^u_k(n+1, h'_k(h,1), a^e_{k,opt}(n,h,a)) \end{aligned} \tag{B.20}$$

and for unemployed workers

$$\begin{aligned} U^u_k(n,h,a) = u(c^u_{k,opt}(n,h,a)) + & \\ & + \beta\zeta_k(s_{k,opt}(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a))) \\ & \quad * U^e_k(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a)) \\ & + \beta[1-\zeta_k(s_{k,opt}(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a)))] \\ & \quad * U^u_k(n+1, h'_k(h,0), a^u_{k,opt}(n,h,a)) \end{aligned} \tag{B.21}$$

Consumption in retirement is constant and consists of government transfers and the annuity income of asset holdings at the beginning of retirement

$$c^r(a) = \pi + T + \frac{(1-\tau^I)r[1+(1-\tau^I)r]^{\bar{n}_r}}{[1+(1-\tau^I)r]^{\bar{n}r}-1}a \tag{B.22}$$

Since utility is entirely generated through consumption in retirement, we have $U_k^e(\bar{n}_w + 1, h, a) = U_k^u(\bar{n}_w + 1, h, a) = \frac{1-\beta^{\bar{n}_r}}{1-\beta} u(c_k^r(h, a))$. Solving backwards using equations ((B.20)–(B.21)) then yields $U_{k,base}^s(0, h_0, a_0)$.

C Calibrations for policy experiments

C.1 Baseline calibration

Table C.1 summarizes the baseline calibration.

Parameter	Definition	Value low	Value medium	Value high
$\bar{n}_w$	Working periods		180	
$\bar{n}_r$	Retirement periods		80	
β	Discount factor		0.99	
σ^c	Risk aversion coefficient for consumption		2.0	
σ^l	Risk aversion coefficient for leisure		2.0	
χ_k	Type share of population	0.11	0.58	0.31
$h'(h, w)$	Human capital production technologies			
α_k	Learning ability parameter	0.03	0.04	0.06
ϕ_k	Human capital curvature parameter	0.10	0.10	0.10
δ_k^h	Human capital depreciation rate	0.03	0.03	0.03
$\zeta_k(s)$	Job search technologies			
α_k	Search technology slope parameter	1.00	1.01	1.09
γ_k	Search technology intercept	0.14	0.12	0.08
$\delta_{k,n}$	Separation rate at age (years)			
	$n = 22.5$	0.079	0.038	0.021
	$n = 27.5$	0.063	0.033	0.013
	$n = 32.5$	0.058	0.030	0.012
	$n = 37.5$	0.055	0.028	0.012
	$n = 42.5$	0.050	0.026	0.013
	$n = 47.5$	0.048	0.025	0.013
	$n = 52.5$	0.043	0.024	0.014
	$n = 57.5$	0.039	0.024	0.016
	$n = 62.5$	0.034	0.023	0.017
π	Retirement pensions		0.67	
T	Lumpsum transfers		0.20	
$\underline{a}$	Borrowing constraint		-1.12	
τ^{UI}	Unemployment insurance tax rate	0.014	0.014	0.014
τ^{SS}	Social security tax rate	0.050	0.050	0.050
τ^I	General income tax rate	0.150	0.150	0.150
$\rho_{k,n}$	UI replacement rate at age (years)			
	$n = 20$	0.50	0.50	0.50
	$n = 31.25$	0.50	0.50	0.50
	$n = 42.5$	0.50	0.50	0.50
	$n = 53.75$	0.50	0.50	0.50
	$n = 65$	0.50	0.50	0.50
b_{min}	UI floor		0.00	
b_{max}	UI cap		inf	

Table C.1: Model parameters in the base calibration

Notes: The functions $\delta_{k,n}$ and $\rho_{k,n}$ are splines through values in the table.

C.2 Policy experiments

Tables C.2– C.6 summarize the calibrations of the policy experiments.

Parameter	Definition	Value low	Value medium	Value high
$\bar{n}_w$	Working periods		180	
$\bar{n}_r$	Retirement periods		80	
β	Discount factor		0.99	
σ^c	Risk aversion coefficient for consumption		2.0	
σ^l	Risk aversion coefficient for leisure		2.0	
χ_k	Type share of population	0.11	0.58	0.31
$h'(h, w)$	Human capital production technologies			
α_k	Learning ability parameter	0.03	0.04	0.06
ϕ_k	Human capital curvature parameter	0.10	0.10	0.10
δ_k^h	Human capital depreciation rate	0.03	0.03	0.03
$\zeta_k(s)$	Job search technologies			
α_k	Search technology slope parameter	1.00	1.01	1.09
γ_k	Search technology intercept	0.14	0.12	0.08
$\delta_{k,n}$	Separation rate at age (years)			
	$n = 22.5$	0.079	0.038	0.021
	$n = 27.5$	0.063	0.033	0.013
	$n = 32.5$	0.058	0.030	0.012
	$n = 37.5$	0.055	0.028	0.012
	$n = 42.5$	0.050	0.026	0.013
	$n = 47.5$	0.048	0.025	0.013
	$n = 52.5$	0.043	0.024	0.014
	$n = 57.5$	0.039	0.024	0.016
	$n = 62.5$	0.034	0.023	0.017
π	Retirement pensions		0.67	
T	Lumpsum transfers		0.20	
$\underline{a}$	Borrowing constraint		-1.12	
τ^{UI}	Unemployment insurance tax rate	0.012	0.012	0.012
τ^{SS}	Social security tax rate	0.050	0.050	0.050
τ^I	General income tax rate	0.150	0.150	0.150
$\rho_{k,n}$	UI replacement rate at age (years)			
	$n = 20$	0.44	0.44	0.44
	$n = 31.25$	0.44	0.44	0.44
	$n = 42.5$	0.44	0.44	0.44
	$n = 53.75$	0.44	0.44	0.44
	$n = 65$	0.44	0.44	0.44
b_{min}	UI floor		0.00	
b_{max}	UI cap		inf	

Table C.2: Model parameters in the calibration with an optimal common and constant replacement rates

Notes: The functions $\delta_{k,n}$ and $\rho_{k,n}$ are splines through values in the table.

Parameter	Definition	Value		
		low	medium	high
$\bar{n}_w$	Working periods		180	
$\bar{n}_r$	Retirement periods		80	
β	Discount factor		0.99	
σ^c	Risk aversion coefficient for consumption		2.0	
σ^l	Risk aversion coefficient for leisure		2.0	
χ_k	Type share of population	0.11	0.58	0.31
$h'(h, w)$	Human capital production technologies			
α_k	Learning ability parameter	0.03	0.04	0.06
ϕ_k	Human capital curvature parameter	0.10	0.10	0.10
δ_k^h	Human capital depreciation rate	0.03	0.03	0.03
$\zeta_k(s)$	Job search technologies			
α_k	Search technology slope parameter	1.00	1.01	1.09
γ_k	Search technology intercept	0.14	0.12	0.08
$\delta_{k,n}$	Separation rate at age (years)			
	$n = 22.5$	0.079	0.038	0.021
	$n = 27.5$	0.063	0.033	0.013
	$n = 32.5$	0.058	0.030	0.012
	$n = 37.5$	0.055	0.028	0.012
	$n = 42.5$	0.050	0.026	0.013
	$n = 47.5$	0.048	0.025	0.013
	$n = 52.5$	0.043	0.024	0.014
	$n = 57.5$	0.039	0.024	0.016
	$n = 62.5$	0.034	0.023	0.017
π	Retirement pensions		0.67	
T	Lumpsum transfers		0.20	
$\underline{a}$	Borrowing constraint		-1.12	
τ^{UI}	Unemployment insurance tax rate	0.012	0.012	0.012
τ^{SS}	Social security tax rate	0.050	0.050	0.050
τ^I	General income tax rate	0.150	0.150	0.150
$\rho_{k,n}$	UI replacement rate at age (years)			
	$n = 20$	0.67	0.67	0.67
	$n = 31.25$	0.52	0.52	0.52
	$n = 42.5$	0.12	0.12	0.12
	$n = 53.75$	0.01	0.01	0.01
	$n = 65$	0.06	0.06	0.06
b_{min}	UI floor		0.00	
b_{max}	UI cap		inf	

Table C.3: Model parameters in the calibration with age-dependent replacement rates

Notes: The functions $\delta_{k,n}$ and $\rho_{k,n}$ are splines through values in the table.

Parameter	Definition	Value low	Value medium	Value high
$\bar{n}_w$	Working periods		180	
$\bar{n}_r$	Retirement periods		80	
β	Discount factor		0.99	
σ^c	Risk aversion coefficient for consumption		2.0	
σ^l	Risk aversion coefficient for leisure		2.0	
χ_k	Type share of population	0.11	0.58	0.31
$h'(h, w)$	Human capital production technologies			
α_k	Learning ability parameter	0.03	0.04	0.06
ϕ_k	Human capital curvature parameter	0.10	0.10	0.10
δ_k^h	Human capital depreciation rate	0.03	0.03	0.03
$\zeta_k(s)$	Job search technologies			
α_k	Search technology slope parameter	1.00	1.01	1.09
γ_k	Search technology intercept	0.14	0.12	0.08
$\delta_{k,n}$	Separation rate at age (years)			
	$n = 22.5$	0.079	0.038	0.021
	$n = 27.5$	0.063	0.033	0.013
	$n = 32.5$	0.058	0.030	0.012
	$n = 37.5$	0.055	0.028	0.012
	$n = 42.5$	0.050	0.026	0.013
	$n = 47.5$	0.048	0.025	0.013
	$n = 52.5$	0.043	0.024	0.014
	$n = 57.5$	0.039	0.024	0.016
	$n = 62.5$	0.034	0.023	0.017
π	Retirement pensions		0.67	
T	Lumpsum transfers		0.20	
$\underline{a}$	Borrowing constraint		-1.12	
τ^{UI}	Unemployment insurance tax rate	0.014	0.014	0.014
τ^{SS}	Social security tax rate	0.050	0.050	0.050
τ^I	General income tax rate	0.150	0.150	0.150
$\rho_{k,n}$	UI replacement rate at age (years)			
	$n = 20$	1.00	0.73	0.52
	$n = 31.25$	0.81	0.52	0.37
	$n = 42.5$	0.63	0.25	0.05
	$n = 53.75$	0.53	0.07	-0.01
	$n = 65$	0.44	0.15	0.09
b_{min}	UI floor		0.00	
b_{max}	UI cap		inf	

Table C.4: Model parameters in the calibration with age-and-type-dependent replacement rates

Notes: The functions $\delta_{k,n}$ and $\rho_{k,n}$ are splines through values in the table.

Parameter	Definition	Value		
		low	medium	high
$\bar{n}_w$	Working periods		180	
$\bar{n}_r$	Retirement periods		80	
β	Discount factor		0.99	
σ^c	Risk aversion coefficient for consumption		2.0	
σ^l	Risk aversion coefficient for leisure		2.0	
χ_k	Type share of population	0.11	0.58	0.31
$h'(h, w)$	Human capital production technologies			
α_k	Learning ability parameter	0.03	0.04	0.06
ϕ_k	Human capital curvature parameter	0.10	0.10	0.10
δ_k^h	Human capital depreciation rate	0.03	0.03	0.03
$\zeta_k(s)$	Job search technologies			
α_k	Search technology slope parameter	1.00	1.01	1.09
γ_k	Search technology intercept	0.14	0.12	0.08
$\delta_{k,n}$	Separation rate at age (years)			
	$n = 22.5$	0.079	0.038	0.021
	$n = 27.5$	0.063	0.033	0.013
	$n = 32.5$	0.058	0.030	0.012
	$n = 37.5$	0.055	0.028	0.012
	$n = 42.5$	0.050	0.026	0.013
	$n = 47.5$	0.048	0.025	0.013
	$n = 52.5$	0.043	0.024	0.014
	$n = 57.5$	0.039	0.024	0.016
	$n = 62.5$	0.034	0.023	0.017
π	Retirement pensions		0.67	
T	Lumpsum transfers		0.20	
$\underline{a}$	Borrowing constraint		-1.12	
τ^{UI}	Unemployment insurance tax rate	0.013	0.013	0.013
τ^{SS}	Social security tax rate	0.050	0.050	0.050
τ^I	General income tax rate	0.150	0.150	0.150
$\rho_{k,n}$	UI replacement rate at age (years)			
	$n = 20$	0.22	0.22	0.22
	$n = 31.25$	0.22	0.22	0.22
	$n = 42.5$	0.22	0.22	0.22
	$n = 53.75$	0.22	0.22	0.22
	$n = 65$	0.22	0.22	0.22
b_{min}	UI floor		0.56	
b_{max}	UI cap		0.69	

Table C.5: Model parameters in the calibration with fixed replacement rates, benefit floor and benefit cap

Notes: The functions $\delta_{k,n}$ and $\rho_{k,n}$ are splines through values in the table.

Parameter	Definition	Value low	Value medium	Value high
$\bar{n}_w$	Working periods		180	
$\bar{n}_r$	Retirement periods		80	
β	Discount factor		0.99	
σ^c	Risk aversion coefficient for consumption		2.0	
σ^l	Risk aversion coefficient for leisure		2.0	
χ_k	Type share of population	0.11	0.58	0.31
$h'(h, w)$	Human capital production technologies			
α_k	Learning ability parameter	0.03	0.04	0.06
ϕ_k	Human capital curvature parameter	0.10	0.10	0.10
δ_k^h	Human capital depreciation rate	0.03	0.03	0.03
$\zeta_k(s)$	Job search technologies			
α_k	Search technology slope parameter	1.00	1.01	1.09
γ_k	Search technology intercept	0.14	0.12	0.08
$\delta_{k,n}$	Separation rate at age (years)			
	$n = 22.5$	0.079	0.038	0.021
	$n = 27.5$	0.063	0.033	0.013
	$n = 32.5$	0.058	0.030	0.012
	$n = 37.5$	0.055	0.028	0.012
	$n = 42.5$	0.050	0.026	0.013
	$n = 47.5$	0.048	0.025	0.013
	$n = 52.5$	0.043	0.024	0.014
	$n = 57.5$	0.039	0.024	0.016
	$n = 62.5$	0.034	0.023	0.017
π	Retirement pensions		0.67	
T	Lumpsum transfers		0.20	
$\underline{a}$	Borrowing constraint		-1.12	
τ^{UI}	Unemployment insurance tax rate	0.005	0.010	0.014
τ^{SS}	Social security tax rate	0.050	0.050	0.050
τ^I	General income tax rate	0.150	0.150	0.150
$\rho_{k,n}$	UI replacement rate at age (years)			
	$n = 20$	0.54	0.62	0.79
	$n = 31.25$	0.43	0.49	0.42
	$n = 42.5$	0.13	0.12	0.11
	$n = 53.75$	0.08	-0.10	0.12
	$n = 65$	0.26	0.06	0.22
b_{min}	UI floor		0.00	
b_{max}	UI cap		inf	

Table C.6: Model parameters in the calibration with age-and-type-dependent replacement rates and UI budget by type fixed to baseline levels

Notes: The functions $\delta_{k,n}$ and $\rho_{k,n}$ are splines through values in the table.

D Computational details

Numerical methods For *age-dependent* and *age-and-type dependent*, replacement rates for all ages are obtained by fitting a cubis Hermite spline through five equally spaced age knots between age $t = 0$ and age $t = 180$ (function values at the knots are given by the respective parameters).

The optimization is conducted using a quasi-Newton algorithm. I use the Broyden-Fletcher-Goldfarb-Shano (BFGS) algorithm to compute the direction of the update step in combination with a backtracking line search algorithm to compute optimal step length. The gradient of the objective function w.r.t. the parameter vector is computed at each step using the two-sided finite differences method. For details on the numerical methods, see Miranda and Fackler (2004). The code to replicate the results is available upon request.

Resources For data handling and regression analyses, I have used *python* (version 3.8.6), *R* (version 4.0.3) and *STATA* (version SE 14.2). Model outputs have been calculated in *python*. In addition, the following software packages have been used:

- *python*:
  - *matplotlib* (version 3.3.3, see Caswell et al. (2020))
  - *numba* (version 0.52.0, see Lam, Pitrou, and Seibert (2015))
  - *numpy* (version 1.19.5, see Oliphant (2006))
  - *pandas* (version 1.2.1, see Reback et al. (2020))
  - *scipy* (version 1.6.0, see Virtanen et al. (2020))
- *R*:
  - *dplyr* (version 1.0.3, see Wickham, François, et al. (2020))
  - *plyr* (version 1.8,6, see Wickham (2011))
  - *stargazer* (version 5.2.2, see Hlavac (2018))
  - *tidyr* (version 1.1.2, see Wickham and Henry (2020))

The project code is embedded in a template for reproducible projects in computational economics by von Gaudecker, 2019.