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

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Preliminary and incomplete.

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The incentives to search for employment vary systematically over the life cycle and with idiosyncratic productivity. These variations should be accounted for when designing UI policy. Using a life cycle model with endogenous human capital accumulation and permanent differences in worker productivity, I assess the welfare implications from optimally setting effective UI replacement rates. Welfare gains are sizeable, both absolute and relative to the size of the program, amounting to up to 0.7% of consumption in all periods and states or roughly 30% of the size of the UI program. Moreover, I demonstrate that the entire gains from conditioning replacement rates on age only and about three quarters of the welfare gains from conditioning on age and productivity can be generated by a simple and robust implementation inspired by the current U.S. UI system, featuring only a constant replacement rate, a benefit floor, and a benefit cap.

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1 Introduction

Unemployment insurance (UI) is a core component of most countries social security system. Targeted at providing public insurance where private insurance markets are incomplete, the policy's policy's importance becomes particularly apparent in times of significant economic downturns: During the Great Recession in 2008, benefit extensions have been one of the major policy responses to support the U.S. labor market and on the onset of the COVID-19 pandemic, benefits applications have skyrocketed in the U.S. and many other countries.

UI provides insurance against income loss through unemployment. Conditioning benefits on pre-unemployment earnings ensures that the level of benefits is appropriate for the household. The generosity of the insurance system is typically governed by the replacement rate, i.e. by how much of the pre-unemployment wage is paid out in benefits.

The optimal level of insurance provided to households depends on age and on idiosyncratic productivity. As search effort is not (perfectly) observable, unemployed workers have a discretionary margin as to how intensely they search for a new job while receiving benefits. Naturally, this gives rise to moral hazard and the optimal level of insurance provided thus depends on two factors: how highly does the worker value publicly provided insurance and how does this affect the workers incentives to search for employment. Both of these factors depend on age and on productivity.

The value of publicly provided insurance increases in the workers' unemployment risk and falls with the workers' ability to self-insure. It is a well-established fact that unemployment risk varies with age and idiosyncratic productivity: unemployment probabilities generally fall over the life-cycle and with the level of education. The ability to self-insure also varies systematically in these dimensions. Self-insurance against income loss is typically obtained through savings. Young workers and low productivity workers often have little to no savings, whereas older workers and highly productive workers are more likely to have accumulated sufficient savings to cushion the income loss from an unemployment spell. Thus, young workers and low productivity workers value publicly provided insurance more highly than older workers and high productivity workers.

The incentives to search for employment are governed by the returns the worker expects from successful search. These come in two forms: immediate income from employment and experience that is valued in the labor market. While public insurance can provide income through benefits, experience can only be obtained on the job. With wages linked to experience, there is a natural investment motive in the labor supply decision: gaining experience today pays off through higher wages tomorrow. This motive differs by age and idiosyncratic productivity: the shape of the wage curve determines the returns to the investment, the remaining working life determines the length of the payoff period. Moreover, evidence on wage losses upon reemployment indicate that the severity of wage loss events is larger for higher skilled workers. Combining these features yields a framework in which labor market risks and labor market opportunities vary both over the life cycle and with worker productivity.

In the U.S., the current UI system is broadly characterized by three key features: a replacement rate on pre-unemployment wages, a benefit floor, and a benefit cap. While the replacement rate has been subject to extensive analysis, the bounds on benefits are usually neglected, arguing that they play a minor role in determining benefits levels. For the average household, this is true. When accounting for heterogeneity between workers, however, the picture changes: Since some groups are more likely to be affected by the bounds than others, the *effective* replacement rate applied to a given subgroup of the population varies substantially with e.g. age and education. At the same time, the literature suggests that UI benefits should be conditional on skill or indicators thereof. For instance, Michelacci and Ruffo (2015) have shown that conditioning replacement rates on age can generate sizeable welfare gains in a framework with endogenous human capital accumulation and wages linked to human capital. In combination, this immediately raises the question about the effects of UI benefit bounds in a framework with richer heterogeneity between workers and how these policies fare relative to policies that explicitly condition on proxies for skill such as age or education.

I begin my study by presenting some empirical evidence on the variations of insurance value of UI and incentives to work by age and by productivity. For the former, I replicate the well-established life-cycle patterns of unemployment probabilities and asset holdings by educational attainment. For the latter, I discuss evidence on returns to experience.

Then, I look at the current U.S. UI system in more detail using CPS data in combination with information on the UI system provided by the Education and Training Administration (ETA). I demonstrate that the system features rich and systematic heterogeneity in effective replacement rates with respect to age and education.

To assess the effects of the policy scheme on labor supply and welfare, I set up a life cycle model with ex-ante differences in idiosyncratic productivity captured by permanent worker types. Productivity differences between types translate into differences in labor market risks and opportunities, reflecting the empirical findings. I calibrate the model to U.S. data and analyse a variety of policy instruments proposed by the literature regarding their implications on welfare. For this, I optimally set classes of parameterized policy functions, including replacement rates that are conditional on age, type, and both, as well as a combination of rate, floor, and cap as currently in place in the U.S..

I find that optimal age-dependent profiles are generally decreasing with age, but much less so for low-productivity workers than for high productivity workers, reflecting the insurance value of UI for low types even in old ages. Moreover, about three quarters of the welfare gains from a fully age-and-type dependent policy, and the entire welfare gains from an age-dependent policy can be obtained by choosing optimal parameters for the rate, floor and cap policy.

The paper proceeds as follows: Section 2 presents further related literature, section 3 presents the empirical findings. Section 4 develops the laboratory economy for policy analysis, demonstrates the solution methods for first best allocation and decentralized economy and presents the calibration of the baseline economy. The performance of the model versus calibration targets and other empirical data, as well as the policy analysis are documented in section 5. 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. Unemployment statistics are obtained from information on individuals' labor force status from the CPS. Throughout this analysis, idiosyncratic productivity is approximated by

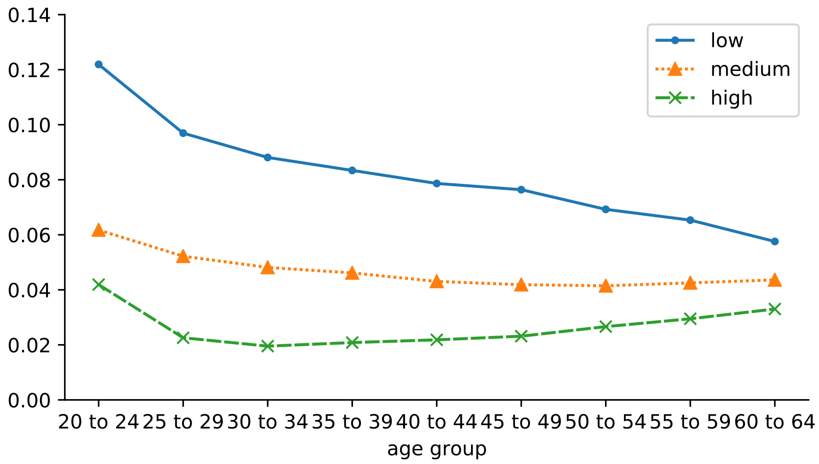


Figure 1: Labor market statistics by age group and educational attainment

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

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 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

[1]For details, see Appendix A

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 *to be completed*

Returns to education and experience *to be completed*

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 by regressing on observables and predicting average conditional effects by age group and education group. Figure 2 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

[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

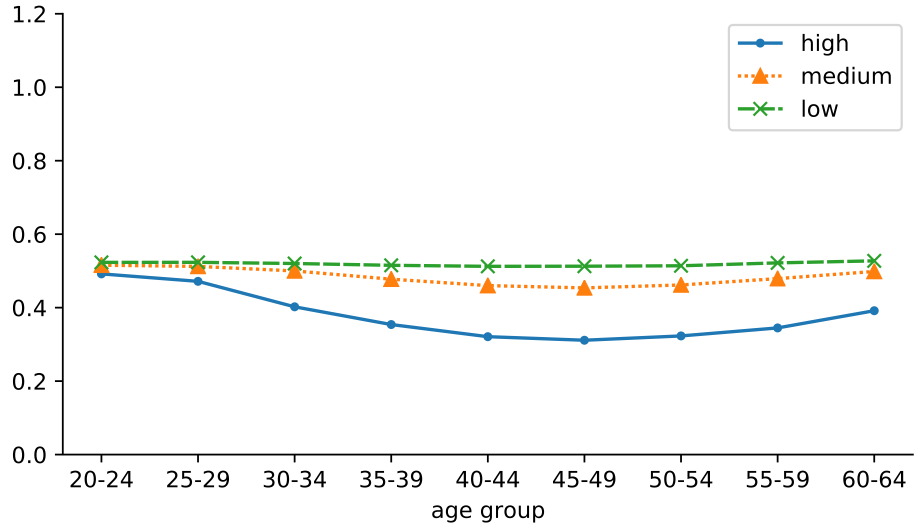


Figure 2: Average effective UI replacement rate by age and education

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.

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 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 straightforward generalization of the model used in Michelacci and Ruffo, 2015. I extend the framework by adding worker types and by generalizing government policies to sets of parameterized income tax functions and UI benefit functions. 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 The total mass of workers is 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 assumed to be constant. 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 are homogeneous in preferences, i.e. all types have a common discount factor β and a common CRRA consumption utility specification $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, with $\sigma > 0$ and identical across types. Preferences for leisure are captured by the function $\phi(l)$ that is strictly increasing and strictly concave in leisure l. I impose preference homogeneity to focus the analysis on differences in labor market behavior stemming from differences in productivity and age only.

Financial markets When workers enter the model, they start with zero initial assets, $a = 0$. 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 $\underline{a}$. In the basic setup, 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.

Labor markets Labor markets are fragmented: employers can observe the type and workers of a given type can only work in their respective labor market. As a consequence, unemployment rates, job separation rates, and contact rates are independent between markets.

Within each labor market, the setup is identical: Employed workers with human capital level h and type k receive wages $\bar{\omega}\omega_k(h)$, where $\bar{\omega}$ is the average wage level and $\omega_k(h)$ is the worker's type-dependent wage-experience-factor. Ability and experience jointly determine wage-experience factors $\omega_k(h)$, with the relationship featuring positive but diminishing returns to experience for all types k ($\frac{\partial \omega_k(h)}{\partial h} \geq 0$ and $\frac{\partial^2 \omega_k(h)}{\partial h^2} \leq 0$). Note that wages do not directly depend on age. They are, however, highly correlated with age, as the only way of accumulating experience is through employment. In every period of employment, workers face the risk of becoming unemployed with exogenous probability $\delta_{k,n}$ that again depends on age and type.

Unemployed workers receive UI benefits b and search for employment. Workers are endowed with one unit of time which they can enjoy as leisure or invest in searching for employment. The search technology is captured by the relationship $\mu = \zeta(s)$, where μ is the probability to find a job and $\zeta : [0,1] \rightarrow [0,1]$ is increasing and concave in s. Successful job search leads to a job in the same period.

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 zero initial human capital, $h = 0$. For every period of employment, workers accumulate one unit of human capital. When unemployed, workers are at risk of experiencing a depreciation of their human capital. The depreciation occurs at most once during each unemployment spell and only materialises when the unemployment spell ends. Depreciation occurs with probability γ, i.e. the probability of human capital depreciation neither depends on type nor age. A worker that has experienced a human capital loss and finds a job in some subsequent period is hired with experience $\kappa_k(n,h) \leq h$. Note that the loss function, $\kappa_k(n,h)$, can differ by type, age, and human capital at the time of the job loss. Modelling skill depreciation in this way induces wage losses upon re-employment that correlate with age and can differ by type. The timing convention that human capital losses materialise upon reemployment simplifies the solution, in that it is only necessary to track *if* a human capital loss has occurred, but not *when* it has taken place. In this framework, earnings loss through unemployment and the human capital loss through skill depreciation are the only source of risk.

Retirement During retirement, the workers receive retirement pensions π, which do not depend on their type, age, assets, human capital, or the earning history. Given the focus on UI in this paper, it is assumed that the government takes pension levels given. These simplifying assumptions are in line with the literature (see e.g. Michelacci and Ruffo, 2015 for an application to UI policy analysis or Conesa, Kitao, and Krueger, 2009 for an application to capital taxation).

Government policy Both types of benefits - pensions and UI - are financed by a proportional income tax. As pensions are assumed to be exogenous, government policy consists of setting income taxes and UI benefits subject to a budget constraint. In the generalized notation, income taxes and unemployment insurance benefits are functions of a workers type, age, and experience, $\tau_k(n,h)$ and $b_k(n,h)$ for $k = 1,\dots,K$. I consider the following sets of policy instruments:

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

Regarding the budget restriction, I assume that the budget needs to be balanced in aggregates only. 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 policy is 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 agents are net payers and some agents 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. Naturally, effects from more efficient search behavior and effects from redistribution blend in such a treatment. In section 5.3, I provide a decomposition of welfare gains stemming from more efficient behavior of individual agents and redistribution across types.

The budget constraint is captured by the condition:

$$\sum_{k=1}^{K}\sum_{n=1}^{\bar{n}_w}\beta^n\int_{R^+} b_k(n,h)\chi_k^u(n,dh) + \sum_{k=1}^{K}\sum_{n=\bar{n}_w}^{\bar{n}_r}\beta^n\pi_k\chi_k^r(n) = \sum_{k=1}^{K}\sum_{n=1}^{\bar{n}_w}\beta^n\int_{R^+}\tau_k(n,h)\chi_k^e(n,dh) \tag{1}$$

where $\chi_k^e(n,dh)$ 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.

The objective function of the government is expected ex-ante present value of utility at entry $\sum_{k\in K}\chi_k V_k^s(0,0,0)$. In other words, the government problem consists in maximizing the expected present value of lifetime utility of a worker prior to drawing the worker's type, subject to the government budget constraint (1).

Household problem At the core of the model is the worker optimization problem. There are two sequential decisions to take in every period: first, unemployed workers decide how much time to invest in job search and how much to enjoy leisure, before all workers decide how much to consume out of their available resources and how much to save. The problem can be captured by five states through which the workers transition. As all workers enter the model without a job, everyone starts in the *searching* state. Successful searchers transition to *employed*, unsuccessful ones to *unemployed*. Workers that are *employed* state at the end of a period either remain employed (with probability $1-\delta_{k.n}$) or transition to the *searching* state. Workers that are *unemployed* at the end of a period either transition to *searching* (with probability $1-\gamma$) or, if they incur a depreciation of their human capital, transition to the state of searching with depreciated skill (*searching**). From the state of searching workers after skill depreciation, search can again either be successful, and the worker transitions to *employed*, or be unsuccessful, in which case they transition to the unemployed with depreciated skill state (*unemployed**). Finally, all workers from unemployed with depreciated skill transition to searching with depreciated skill.

Searching workers face a trade-off between enjoying leisure, from which they receive utility, and exerting effort to find a job: More time invested in search yields a higher probability to find a job at the cost of lower utility from leisure. For ease of notation, leisure utility and search technology are combined into an implicit leisure utility function $\psi(\mu)$ that expresses leisure utility as a function of the probability to find a job in the given period. From the assumptions on leisure utility and search technology, it follows that ψ is strictly decreasing and strictly concave in μ (for more details, see Appendix B). Searching workers then directly choose the probability to find a job, accounting for the above trade-off.

In the model, the above trade-off is represented by unemployed workers of type k directly choosing their probability to become employed in the given period, μ_k, which in turn determines the implicit utility from leisure $\psi_k(\mu_k)$ that accounts for both preferences on leisure and the worker's search technology. To ensure uniqueness of the optimal level of search effort, it is assumed that implicit utility from leisure is strictly decreasing and strictly concave in μ ($\frac{\partial\psi}{\partial\mu} < 0$ and $\frac{\partial^2\psi}{\partial\mu^2} < 0$, respectively). These assumptions, while in part motivated by tractability, relate to the ideas that leisure is a normal good and that the job search technology has positive but decreasing returns to search effort, both of which are standard assumptions in the literature.[3] As implicit leisure utility incorporates search technology, which may depend on a worker's ability, the implicit utility functions are potentially type-dependent even though we assume preference homogeneity.

The worker maximization problem in the decentralized economy can be represented by a set of five value functions for each type k, corresponding to the five states a worker can be in within a given period. Denote by $c_k^e(n,h,a,a')$, $c_k^u(n,h,a,a')$, and $c_k^*(n,h,h,a')$ the consumption levels of an employed worker, unemployed worker, and worker whose skill has depreciated, with age n, human capital h, current assets a, and next periods

[3]For a formal derivation of the implicit leisure function and its properties from the assumptions on search technology and preferences for leisure, see appendix B.

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 $V_k^u(n,h,a)$, $V_k^{u*}(n,h,a)$, $V_k^s(n,h,a)$, and $V_k^{s*}(n,h,a)$ the same quantity for unemployed workers without human capital loss, unemployed workers with human capital loss, searching workers without human capital loss, and searching workers with human capital loss, 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:

$$V_k^e(n,h,a) = \max_{a' \geq \underline{a}} u(c_k^e(n,h,a,a')) + \beta \Big[(1-\delta_{k,n}) V_k^e(n+1,h+1,a') + \delta_{k,n} V_k^s(n+1,h+1,a') \Big] \tag{2}$$

The value of being in the *searching* state (i.e. without having suffered a depreciation of human capital) is given by the sum of implicit 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:

$$V_k^s(n,h,a) = \max_{\mu_k^s \in [0,1]} \psi(\mu_k^s) + \mu_k^s V_k^e(n,h,a) + (1-\mu_k^s) V_k^u(n,h,a) \tag{3}$$

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

$$V_k^u(n,h,a) = \max_{a' \geq \underline{a}} u(c_k^u(n,h,a,a')) + \beta \Big[(1-\gamma_k) V_k^s(n+1,h,a') + \gamma_k V_k^{s*}(n+1,h,a') \Big] \tag{4}$$

which is the sum of consumption under unemployment and the expected discounted value from either transitioning to *searching* or suffering a skill depreciation event and transitioning to *searching**, again given that assets are chosen optimally.

The value function for a searching worker that experienced a skill depreciation is given by the sum of implicit leisure utility and the expected value of a transition to either being *employed* (with a depreciated level of human capital $\kappa_k(n,h)$) or being unemployed after having suffered from skill depreciation, *unemployed**:

$$V_k^{s*}(n,h,a) = \max_{\mu_k^{s*} \in [0,1]} \psi(\mu_k^{s*}) + \mu_k^{s*} V_k^e(n,\kappa_k(n,h),a) + (1-\mu_k^{s*}) V_k^{s*}(n,h,a) \tag{5}$$

Finally, the value of being unemployed after having suffered from skill depreciation (*unemployed**), is the sum of consumption in state *unemployed** and the discounted value of transitioning to state *searching**

$$V_k^{u*}(n,h,a) = \max_{a' \geq \underline{a}} u(c_k^{u*}(n,h,a,a')) + \beta V_k^{s*}(n+1,h,a') \tag{6}$$

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

$$c_k^e(n,h,a,a') = \bar{\omega}\omega_k(h) - \tau_k(n,h) + (1+r)a - a' \tag{7}$$

where $\bar{\omega}$ is the wage level, $\omega_k(h)$ is the wage-experience-factor of a worker of type k with human capital h and $\tau_k(n,h)$ is the tax function imposed by the policymaker. As a potential skill depreciation only materialises upon re-employment, consumption when unemployed is the same whether the worker's skills will depreciate or not. From the budget constraint it then again follows that

$$c_k^u(n,h,a,a') = c_k^{u*}(n,h,a,a') = b_k(n,h) + (1+r)a - a' \tag{8}$$

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, $c_k^r(a) = \pi_k + \frac{ra}{1-\beta^{\bar{n}_r}}$, in every period. Consumption during retirement thus only depends on the level of pensions, π_k, and the asset level upon retirement, but neither on the workers acquired human capital h 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 type k is then given by

$$V_k^e(\bar{n}_w+1,h,a) = V_k^u(\bar{n}_w+1,h,a) = V_k^{u*}(\bar{n}_w+1,h,a) = \frac{1-\beta^{\bar{n}_w}}{1-\beta} u(c_k^r(a)) \tag{9}$$

Recall that workers enter the model without a job and without physical or human capital. Thus, after the type of a worker has materialized, the expected discounted value of lifetime utility for that worker is given by $V_k^s(0,0,0)$. The objective of the government is thus defined as expected present value of total utility at model entry (i.e. prior to drawing the type), $\sum_{k \in K} \chi_k V_k^s(0,0,0)$.

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

4.2 Calibration and model fit

The model is calibrated to male individuals in the U.S. and parameters are obtained through a form of indirect inference (see for example Gourieroux, Monfort, and Renault, 1993).

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. Wage-experience factors $\omega_k(h)$ 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 wages 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].

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

In the second step, the wage-experience-function for each type is calibrated such that simulated average wages match the estimated empirical targets. The wage-experience function is parameterized as a cubic spline through ten equally spaced experience knots between $h = 0$ and $h = 180$. Furthermore, the wage-experience-functions are restricted to be non-decreasing, and to be constant for workers aged 60 years and older, The calibrated parameters are summarized in Table C.1, the resulting functions for wage-experience-factors are depicted in figure C.1d.

Separation probabilities Contrasting to the original setup of Michelacci and Ruffo (2015), 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 fit a spline function through the averages described above. The knots of the spline correspond to the average age in the respective age group. The calibrated parameters are summarized in Table C.1, the resulting functions for wage-experience-factors are depicted in figure C.1c.

Wage Losses Upon Reemployment The risk of skill depreciation is captured by two components: the probability of incurring a loss, γ_k, and the loss function in case a depreciation has occurred $\kappa_k(n, h)$. I take the probability of incurring a loss of human capital from Michelacci and Ruffo (2015), setting the value to $\gamma_k = 0.4$ for all k.

For the wage loss function, I again use the calibration from Michelacci and Ruffo (2015) and adjust it for productivity types. For this, I impose the additional assumption that the human capital loss function is independent of worker types. Upon a human capital loss event, a fraction of the current human capital stock of the worker depreciates, and this fraction depends on the worker's age and pre-loss human capital level, but not on the worker's type. Note that identical human capital losses nonetheless translate into different wage losses due to differences in wage-experience-factors between types. Generally speaking, this will result in larger wage losses for higher productive workers. This is in line with the findings of Davis and Wachter (2011) and Johnson and Mommaerts (2011) who find that wage losses upon displacement are (i) increasing with age and (ii) increasing with education.

The calibration in Michelacci and Ruffo (2015) is based on observed average wage losses, i.e. not differentiating by worker type. To adjust this calibration for worker types, it is therefore necessary to construct reference wage-experience-factors representing the average worker. Let $\bar{\omega}(h)$ denote the average wage-experience factor (weighted by population weights of the types) of a worker with human capital level h. The human capital loss function is then given by

$$\kappa(n,h) = \bar{\omega}^{-1}(\bar{\kappa}_n \bar{\omega}(h)) \tag{10}$$

independent of type k, where $\bar{\omega}^{-1}(\cdot)$ is the inverse of the average wage-experience function[5] and $\bar{\kappa}_n$ is the age-dependent human capital depreciation factor. This depreciation factor is parameterized as a spline function[6], where the parameters are taken from the Michelacci and Ruffo (2015). The calibrated parameters of the human capital loss function are summarized in Table C.1, and the resulting function is depicted in figure C.1b.

Implicit leisure utility Combining search technology and preferences for leisure into a single implicit leisure utility function is convenient in terms of notation and model solution, but, as a consequence, does not allow for calibration directly to observable data. However, note that the search effort decision and the derivative of the implicit leisure utility function are linked via first order conditions of the household problem. Since separation probabilities are calibrated directly to the data, search effort and, therefore, the derivative of implicit leisure utility are identified by observed unemployment probabilities. I thus model the derivative of the implicit leisure utility, ϕ', as a five-knot cubic hermite spline and set the values at the knots such as to match empirical unemployment

[5] given the assumptions on wages, $\bar{\omega}^{-1}(\cdot)$ is well defined.

[6] a cubic spline with five knots at $n = 1, 40, 80, 160, 160$

probabilities over age and type. The leisure utility function ϕ is then derived from its derivative with the additional normalization condition $\phi(0) = 0$. This condition entails the idea that a transition that includes losing a job and finding a job in the same period must yield a lower total utility than remaining employed.

I calibrate a single implicit leisure utility function for all types, meaning that in addition to preference homogeneity, I assume that all types use the same search technology. The fit of simulated unemployment rates to calibration targets is depicted in panels (d) to (f) of figure 3. The close fit of model output and observed data supports the assumptions made above.

Remaining Preferences Workers have homogeneous preferences: all workers have common discount factor $\beta = 0.99$ which is set to match annual interest rates of approximately 4 percent and CRRA consumption utility with preference parameter $\sigma = 2.0$, which is common for specifications with separable consumption and leisure utility (see e.g. Conesa, Kitao, and Krueger (2009)).

Borrowing limit The borrowing limit is also 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 In the base calibration, government policy is given by a common and constant UI replacement rate, a common and constant retirement pension level, and a common and constant income tax rate to finance both types of benefits. The UI replacement rate is set to $\bar{\rho} = 0.5$, which is well in line with the empirical findings in section 3 and comparable studies in the literature (see e.g. Chetty, 2008). Retirement pensions are calibrated by matching the empirical ratio of retirement pensions over mean quarterly labor income. According to OECD (2007), this ratio is at around 0.4 for the U.S., which corresponds to a retirement pension level of $\pi = 0.662$. The income tax rate is chosen endogenously to keep the government budget condition (??) balanced. In equilibrium, the base calibration requires the income tax rate to be $\tau = 6.6\%$.

The complete calibration is summarized in table C.1 in the Appendix.

Figure 3 depicts the model fit of key variables by worker type. Figures 3a – 3c show 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.[7] The model matches the empirical profiles closely, both in terms of shape and level. One difference between model and data is that wage profiles in the model are, by construction, non-decreasing. Therefore, they fail to replicate the decrease in empirical wage curves for workers close to retirement.

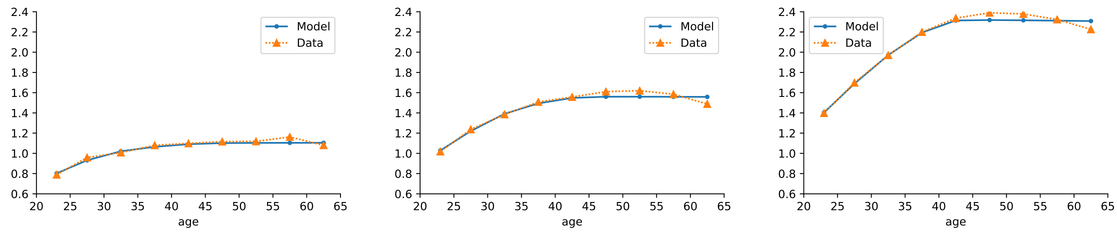
Figures 3d – 3f show simulated unemployment rates versus their empirical counterpart. The empirical targets correspond to the unemployment probabilities presented in section 4.1. The simulated unemployment rates match the data very well. Since separation rates are matched exactly, unemployment probabilities are pinned down by the endogenous job finding rates. These are in turn determined by the implicit leisure utility. The good fit between simulated and empirical unemployment probabilities thus supports the assumptions made for leisure utility (preference homogeneity) and search technology (identical technology for all types).

5 Results

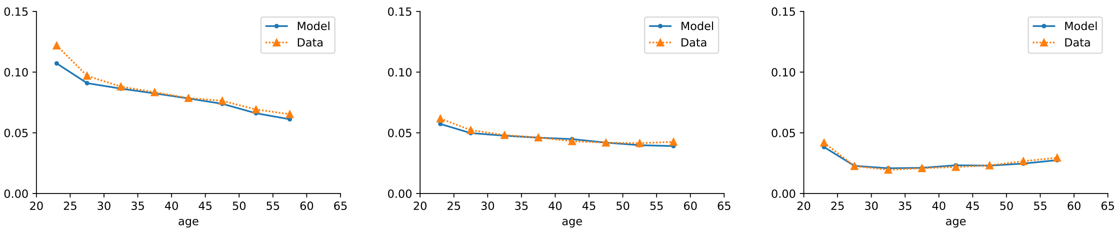
5.1 Policy experiments

I now consider the policy functions presented in section 4 and compute optimal parameters.[8] 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

[7] For the construction of the empirical wage profiles, see section 4.1.
[8] For more information on the optimization routine, see Appendix D.



(a) wages (low) (b) wages (medium) (c) wages (high)



(d) unemployment (low) (e) unemployment (medium) (f) unemployment (high)

Figure 3: Fit of model outputs with observed data.

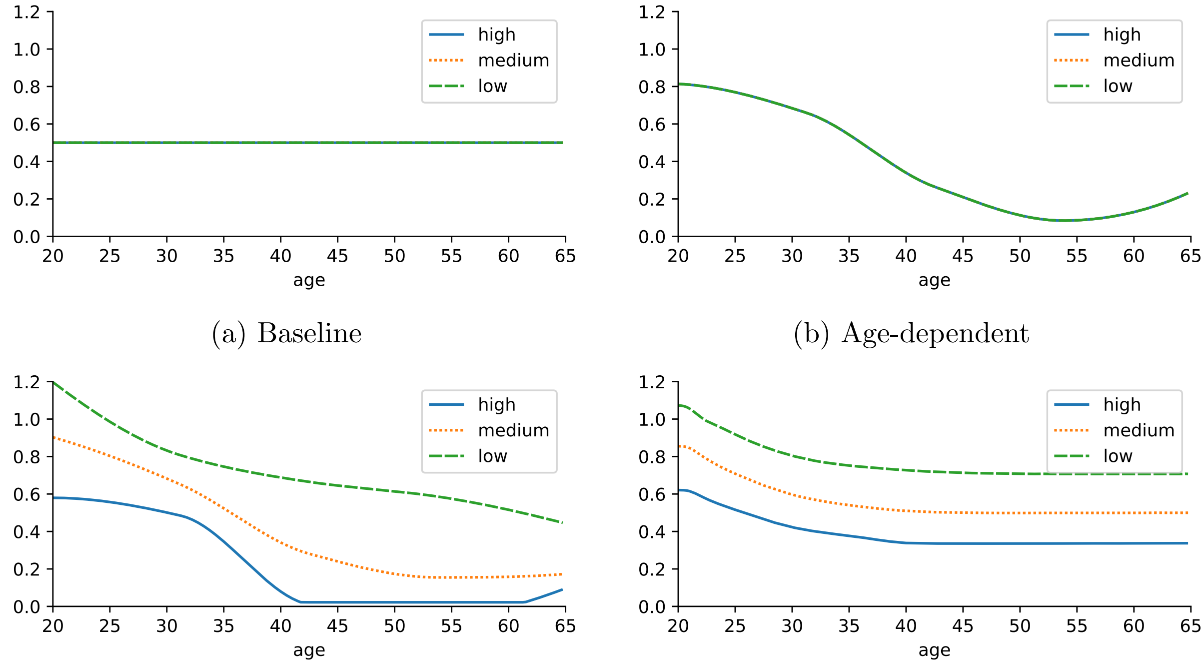
Notes: Panels (a) to (c) depict simulated wages vs. empirical targets. Panels (d) to (f) depict simulated unemployment rates vs. empirical targets.

robust, and, as the basic features are already in place in the U.S., implementation would not require major policy reforms.

Figure 4 depicts the resulting life-cycle profiles of effective replacement rates. For the scenarios *baseline*, *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 4b). 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 (see section 5.3 for a discussion of these two components).

As we have already seen in section 3, the simple structure consisting of a fixed and



(a) Baseline (b) Age-dependent

(c) Age-and-type dependent (d) Rate, floor and cap

Figure 4: Optimal policies: Effective replacement rates

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 4c). 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. Following Michelacci and Ruffo (2015), the welfare analysis is conducted using consumption equivalents. These 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 off as under the alternative setup, while keeping all other quantities constant. Throughout this exercise, the leisure / search cost component of utility is assumed to remain constant during this exercise. To extend the approach

Policy	Consumption equivalent low	medium	high	average
Baseline	0.00	0.00	0.00	0.00
Age-dependent	0.48	0.46	0.63	0.50
Age-and-type-dependent	1.68	0.49	0.75	0.74
Constant rate, floor and cap	1.39	0.32	0.67	0.57

Table 1: Consumption equivalents of optimal implementations of policy instruments

Notes: Consumption equivalents are calculated using equation B.24. The reference scenario for all equivalents is the *baseline* calibration. Average consumption equivalents are obtained as weighted average over types.

to multiple worker types, I fist compute consumption equivalents for all types. I then average over types using population weights to produce an aggregate measure of the welfare change induced by a given policy choice. Note that this average measure cannot be interpreted in the same way as type-specific consumption equivalents: Due to concavity of consumption utility, multiplying consumption levels of all types with the average consumption equivalent while keeping leisure utility constant does not yield the same expected present value of lifetime utility as the alternative scenario. The measure should therefore only be considered as a proxy for the effect on the average worker.

Table 1 summarizes the results of the welfare comparison. First, note that the welfare gains from imposing the first best allocation would be substantial: the average consumption equivalent amounts to almost 8 percent. There are, however, enormous differences by type. While low productivity workers - the net receivers of transfers - would be as well off as under a 61 percent increase of consumption in all states and periods, the high type workers - the net payers of transfers - would be indifferent between the first best allocation and a 23 percent cut in consumption in all states and periods. This exemplifies the scale of the redistribution imposed by the first best allocation.

Contrasting to this, all types are better off under any of the optimal[9] decentralized allocations. Note that the baseline allocation also features a limited degree of redistribution across types: high types less frequently benefit from UI as they are less likely to become unemployed and, in case of unemployment, stay unemployed for shorter time spans. The positive consumption equivalents for all types then indicate that, although all the policies

[9]within the given class of policy instruments

feature some degree of redistribution and part of the welfare gains arise because of that, the change in redistribution relative to baseline is small compared to the effect of more efficient behavior by the workers.

In terms of average consumption equivalents, the welfare effect of optimally setting a common and constant replacement rate is negligible, repeating the aforementioned results that U.S. UI policy is close to optimal on average. The gains from optimally setting type-dependent replacement rates appear minor relative to the total potential gains from the first best, yet this policy already generates one quarter of the gains from an age-and-type-dependent replacement rate. The average consumption equivalent corresponding to optimally setting age-dependent replacement rates is 0.5 percent. This is in line with the original study of Michelacci and Ruffo (2015). As expected, additionally conditioning the replacement rate on worker type further increases the welfare gains, yet the increase is relatively small, to 0.65 percent.

Remarkably, the welfare gains from imposing an optimal combination of common and constant replacement rate, benefit floor and benefit cap are as large as the gains from conditioning the replacement rate on age only and about three quarters of the gains from conditioning the replacement rate on both age and type.

5.3 Welfare decompositions

As mentioned before, when unemployment risks differ across workers, income-tax financed UI systems feature some degree of redistribution by design. These distributional effects are not the primary goal of the policy and if the policymaker wants to redistribute resources, other instruments are better suited. In most cases, changing UI policy also changes the degree of redistribution embedded in the system. To assess alternative policies, it is therefore important to differentiate the welfare effects from resolving the friction (here: unobservable search effort) and redistribution. For this, I compute optimal age-and-type-dependent replacement rates, holding the UI budget by type constant. In other words, I compute optimal age-and-type-dependent replacement rates in an economy with the same net transfers (in present value) across types as the baseline economy. The resulting profiles of replacement rates are depicted in figure 5.

The corresponding consumption equivalents are summarized in Table 2.

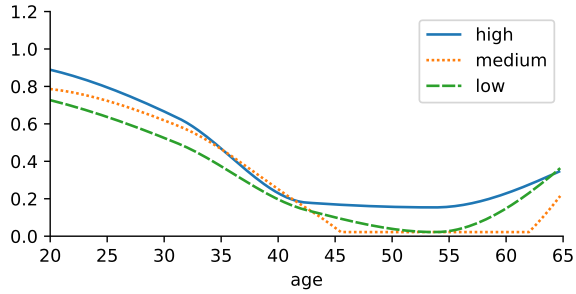


Figure 5: Optimal replacement rates (fixed budget)

Policy	Consumption equivalent low	medium	high	average
Age and type dependent	1.68	0.49	0.75	0.74
Age and type dependent (fixed budget)	0.36	0.48	0.56	0.48
Baseline	0.00	0.00	0.00	0.00

Table 2: Consumption equivalents of optimal implementations of policy instruments (with redistribution across types)

Notes: Consumption equivalents are calculated using equation B.24. The reference scenario for all equivalents is the *baseline* calibration. Average consumption equivalents are obtained as weighted average over types.

As expected from the replacement rate profiles, consumption equivalents of optimal rates under fixed budget are close to the equivalents from optimal age-dependent replacement rates. This indicates that the additional welfare gain from conditioning on worker type stems primarily from more redistribution.

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 sizable 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[10]. 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

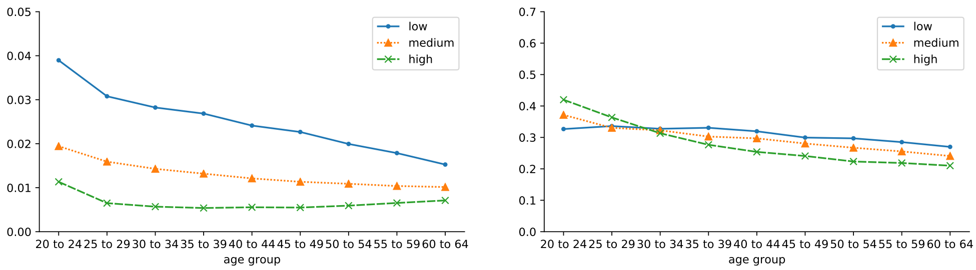
[10] Employment and Training Administation (1989–2020)

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.

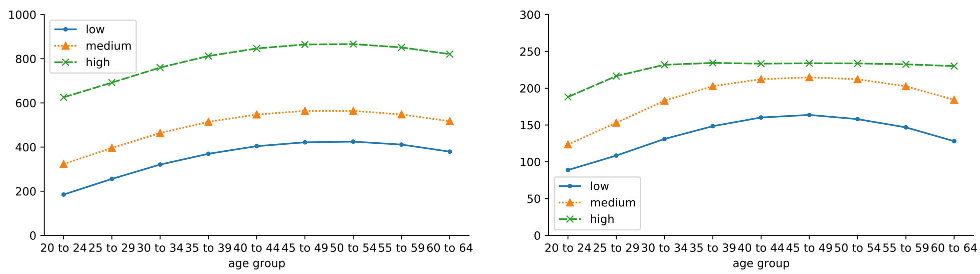


(a) employed-to-unemployed (b) unemployed-to-employed

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.



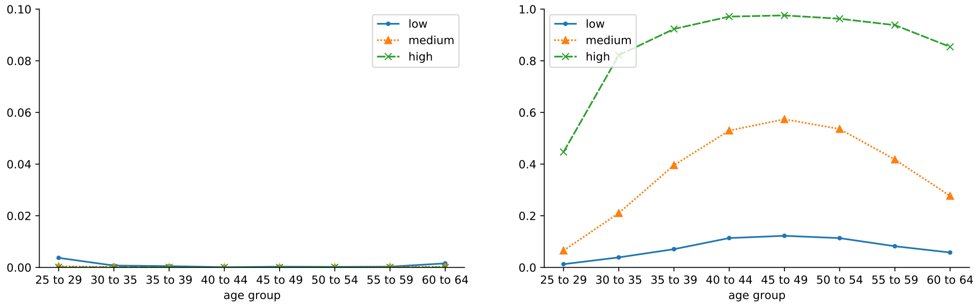
(a) imputed pre-unemployment earnings (b) imputed UI benefits

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 Properties of the leisure utility function

The time endowment of unemployed workers is normalized to 1. It can be invested in job search or in enjoying leisure, where the share of hours spent searching is denoted s and the share of hours spent enjoying leisure is denoted $l = 1 - s$. Utility from leisure is captured by the function $\phi(l)$ that is increasing and concave in l, i.e. $\phi'(l) > 0$ and $\phi''(l) < 0$. Search effort is transformed into the probability of finding a job μ through the search technology $\zeta(s)$, that is increasing and concave in s, i.e. $\zeta'(s) > 0$ and $\zeta''(s) < 0$. Using the formula for search technology, we can express search effort as a function of the job finding probability

$$s = \zeta^{-1}(\mu) \tag{B.1}$$

Note that existence of the inverse of the search technology function follows from above assumptions. Combining this expression with the time endowment constraint, we obtain the implicit utility from a given job finding probability as

$$\psi(\mu) = \phi(1 - \zeta^{-1}(\mu)) \tag{B.2}$$

Taking derivatives w.r.t. μ, we obtain

$$\frac{\partial \psi(\mu)}{\partial \mu} = \frac{\partial}{\partial \mu}\Big(\phi\big(1 - \zeta^{-1}(\mu)\big)\Big) = -\frac{\phi'(l)}{\zeta'(s)} \tag{B.3}$$

and

$$\frac{\partial^2 \psi(\mu)}{\partial \mu^2} = \frac{\partial}{\partial \mu}\left(\frac{\phi'(1 - \zeta^{-1}(\mu))}{\zeta'(\zeta^{-1}(\mu))}\right) = \frac{\phi''(l) + \phi'(l)\frac{\zeta''(s)}{\zeta'(s)}}{[\zeta'(s)]^2} \tag{B.4}$$

Since leisure utility is strictly increasing in l, and search technology is strictly increasing in s, it follows directly that implicit leisure utility is strictly increasing in the job finding probability μ, $\frac{\partial \psi}{\partial \mu} < 0$. Given the strict concavity of both leisure utility and search technology, it also follows that implicit leisure utility is strictly concave in the probability to find a job μ, $\frac{\partial^2 \psi}{\partial \mu^2} < 0$.

B.2 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.

Starting with employed workers, let $a^e_{k,opt}(n,h,a)$ be the asset choice that solves the maximization problem in a given period. For interior solutions, $a^e_{k,opt}(n,h,a)$ thus satisfies

$$-u'(c^e_k(n,h,a,a')) + \beta(1-\delta_{k,n})\frac{\partial V^e_k(n+1,h+1,a')}{\partial a'} + \beta\delta_{k,n}\frac{\partial V^u_k(n+1,h+1,a')}{\partial a'} \overset{!}{=} 0 \tag{B.5}$$

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

$$\begin{aligned} V^e_k(n,h,a) = u(c^e_k(n,h,a,a^e_{k,opt}(n,h,a))) + \beta\Big[&(1-\delta_{k,n})V^e_k(n+1,h+1,a^e_{k,opt}(n,h,a)) \\ &+ \delta_{k,n}V^u_k(n+1,h+1,a^e_{k,opt}(n,h,a))\Big] \end{aligned} \tag{B.6}$$

Taking derivatives w.r.t. a yields

$$\begin{aligned} \frac{\partial V^e_k(n,h,a)}{\partial a} =& \frac{\partial c^e_k(n,h,a,a^e_{k,opt}(n,h,a))}{\partial a}u'(c^e_k(n,h,a,a^e_{k,opt}(n,h,a)) \\ &+ \frac{\partial c^e_k(n,h,a,a^e_{k,opt}(n,h,a))}{\partial a'}\frac{\partial a^e_{k,opt}(n,h,a)}{\partial a}u'(c^e_k(n,h,a,a^e_{k,opt}(n,h,a)) \\ &+ \beta(1-\delta_{k,n})\frac{\partial a^e_{k,opt}(n,h,a)}{\partial a}\frac{\partial V^e_k(n+1,h+1,a^e_{k,opt}(n,h,a))}{\partial a'} \\ &+ \beta\delta_{k,n}\frac{\partial a^e_{k,opt}(n,h,a)}{\partial a}\frac{\partial V^u_k(n+1,h+1,a^e_{k,opt}(n,h,a))}{\partial a'} \\ =&(1+r)u'(c^e_k(n,h,a,a^e_{k,opt}(n,h,a)) + \frac{\partial a^e_{k,opt}(n,h,a)}{\partial a}\Bigg[\\ &- u'(c^e_k(n,h,a,a^e_{k,opt}(n,h,a)) \\ &+ \beta(1-\delta_{k,n})\frac{\partial V^e_k(n+1,h+1,a^e_{k,opt}(n,h,a))}{\partial a'} \\ &+ \beta\delta_{k,n}\frac{\partial V^u_k(n+1,h+1,a^e_{k,opt}(n,h,a))}{\partial a'}\Bigg] \\ =&\frac{1}{\beta}u'(c^e_k(n,h,a,a^e_{k,opt}(n,h,a)) \end{aligned} \tag{B.7}$$

where the last step uses the envelope condition (B.5). Analogously, again making use of the respective envelope conditions on optimal asset policies, we obtain

$$\frac{\partial V^u_k(n,h,a)}{\partial a} = \frac{1}{\beta}u'(c^u_k(n,h,a,a^u_{k,opt}(n,h,a)) \tag{B.8}$$

and

$$\frac{\partial V_k^{u*}(n,h,a)}{\partial a} = \frac{1}{\beta} u'(c_k^{u*}(n,h,a,a_{k,opt}^{u*}(n,h,a)) \tag{B.9}$$

Now, let $\mu_{k,opt}^s(n,h,a)$ solve the maximization problem in equation (3). This implies that, for interior solutions, $\mu_{k,opt}^s(n,h,a)$ satisfies

$$\psi'(\mu_{k,opt}^s(n,h,a)) + V_k^e(n,h,a) - V_k^u(n,h,a) \stackrel{!}{=} 0 \tag{B.10}$$

Again substituting the solution for the maximum operator, the value function for searching workers without human capital loss becomes

$$V_k^s(n,h,a) = \psi(\mu_{k,opt}(n,h,a)) + \mu_{k,opt}^s(n,h,a)V_k^e(n,h,a) + [1-\mu_{k,opt}^s(n,h,a)]V_k^u(n,h,a)$$

Taking derivatives w.r.t. current asset holdings a yields

$$\begin{aligned}
\frac{\partial V_k^s(n,h,a)}{\partial a} =& \frac{\partial \mu_{k,opt}^s(n,h,a)}{\partial a}\psi'(\mu_{k,opt}^s(n,h,a)) \\
&+ \frac{\partial \mu_{k,opt}^s(n,h,a)}{\partial a}V_k^e(n,h,a) + \mu_{k,opt}^s(n,h,a)\frac{\partial V_k^e(n,h,a)}{\partial a} \\
&- \frac{\partial \mu_{k,opt}^s(n,h,a)}{\partial a}V_k^u(n,h,a) + [1-\mu_{k,opt}^s(n,h,a)]\frac{\partial V_k^u(n,h,a)}{\partial a} \\
=& \mu_{k,opt}^s(n,h,a)\frac{\partial V_k^e(n,h,a)}{\partial a} + [1-\mu_{k,opt}^s(n,h,a)]\frac{\partial V_k^u(n,h,a)}{\partial a} \\
&+ \frac{\partial \mu_{k,opt}^s(n,h,a)}{\partial a}\Big[\psi'(\mu_{k,opt}^s(n,h,a)) + V_k^e(n,h,a) - V_k^u(n,h,a)\Big] \\
=& \frac{1}{\beta}\Big[\mu_{k,opt}^s(n,h,a)u'(c_k^e(n,h,a,a_{k,opt}^e(n,h,a)) \\
&+ [1-\mu_{k,opt}^s(n,h,a)]u'(c_k^u(n,h,a,a_{k,opt}^u(n,h,a))\Big]
\end{aligned}$$

where the next to last line employs envelope condition (B.10), and the last line substitutes the expressions for the derivatives of the value functions derived above. Analogously, for searching workers with human capital loss, the optimal search effort level satisfies

$$\psi'(\mu_{k,opt}^{s*}(n,h,a)) + V_k^e(n,h,a) - V_k^{u*}(n,h,a) \stackrel{!}{=} 0 \tag{B.11}$$

and the derivative of the value function for these workers is given by

$$\begin{aligned}
\frac{\partial V_k^{s*}(n,h,a)}{\partial a} =& \frac{1}{\beta}\Big[\mu_{k,opt}^{s*}(n,h,a)u'(c_k^e(n,\kappa_{k,n}(h),a,a_{k,opt}^e(n,\kappa_{k,n}(h),a)) \\
&+ [1-\mu_{k,opt}^{s*}(n,h,a)]u'(c_k^{u*}(n,h,a,a_{k,opt}^u(n,h,a)))\Big]
\end{aligned} \tag{B.12}$$

With these expressions for the derivatives of the value functions ((B.7)–(B.12)), it is straightforward to compute the first order conditions for interior solutions to the consumption / savings choice. Let $a_k^e(n,h,a)$, $a_k^u(n,h,a)$, and $a_k^{u*}(n,h,a)$ denote the optimal asset choice for employed workers, unemployed workers without human capital loss and unemployed workers with human capital loss, respectively. Let

$$c^e_{k,opt}(n,h,a) = c^e_k(n,h,a,a^e_{k,opt}(n,h,a))$$
$$c^u_{k,opt}(n,h,a) = c^u_k(n,h,a,a^u_{k,opt}(n,h,a))$$
$$c^{u*}_{k,opt}(n,h,a) = c^{u*}_k(n,h,a,a^{u*}_{k,opt}(n,h,a))$$

denote the corresponding optimal consumption choices. Imposing the optimality conditions defining $a^e_{k,opt}$, $a^u_{k,opt}$, $a^{u*}_{k,opt}$, $\mu^s_{k,opt}$, and $\mu^{s*}_{k,opt}$ for all periods, we have

$$\begin{aligned}
-u'(c^e_k(n,h,a,a')) + \beta\delta_{k,n}\frac{\partial V^e_k(n+1,h+1,a')}{\partial a'} + \beta(1-\delta_{k,n})\frac{\partial V^s_k(n+1,h+1,a')}{\partial a'} &\overset{!}{=} 0\\
\Leftrightarrow u'(c^e_{k,opt}(n,h,a)) = \beta\delta_{k,n}\frac{\partial V^e_k(n+1,h+1,a')}{\partial a'} + \beta(1-\delta_{k,n})\frac{\partial V^s_k(n+1,h+1,a')}{\partial a'}&\\
\Leftrightarrow u'(c^e_{k,opt}(n,h,a)) =& (1-\delta_{k,n})u'(c^e_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a)))\\
&+\delta_{k,n}\Big[\mu^s_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a))u'(c^e_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a))\\
&+[1-\mu^s_{k,opt}(n+1,h+1,a)]u'(c^u_{k,opt}(n+1,h+1,a^u_{k,opt}(n,h,a)))\Big]
\end{aligned}$$

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

$$\begin{aligned}
c^e_{k,opt}(n,h,a) =& \Big[(1-\delta_{k,n})c^e_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a))^{-\sigma}\\
&+\delta_{k,n}[\mu^s_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a))c^e_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a))^{-\sigma}\\
&+(1-\mu^s_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a)))c^u_{k,opt}(n+1,h+1,a^e_{k,opt}(n,h,a))^{-\sigma}]\Big]^{-\frac{1}{\sigma}}
\end{aligned} \tag{B.13}$$

The first-order conditions for consumption of unemployed workers without human capital loss and with human capital loss, respectively, are derived analogously and are given by

$$\begin{aligned}
c^u_{k,opt}(n,h,a) =& \Big[(1-\gamma_k)[\mu^s_{k,opt}(n+1,h,a^u_{k,opt}(n,h,a))c^e_{k,opt}(n+1,h,a^u_{k,opt}(n,h,a))^{-\sigma}\\
&+(1-\mu^s_{k,opt}(n+1,h,a^u_{k,opt}(n,h,a)))c^u_{k,opt}(n+1,h,a^u_{k,opt}(n,h,a))^{-\sigma}]\\
&+\gamma_k[\mu^{s*}_{k,opt}(n+1,h,a^u_{k,opt}(n,h,a))c^e_{k,opt}(n+1,\kappa_{k,n}(h),a^u_{k,opt}(n,h,a))^{-\sigma}\\
&+(1-\mu^{s*}_{k,opt}(n+1,h,a^u_{k,opt}(n,h,a)))c^{u*}_{k,opt}(n+1,h,a^u_{k,opt}(n,h,a))^{-\sigma}]\Big]^{-\frac{1}{\sigma}}
\end{aligned} \tag{B.14}$$

and

$$\begin{aligned}
c^{u*}_{k,opt}(n,h,a) =& \Big[\mu^{s*}_{k,opt}(n+1,h,a^{u*}_{k,opt}(n,h,a))c^e_{k,opt}(n+1,\kappa_{k,n}(h),a^{u*}_{k,opt}(n,h,a))^{-\sigma}\\
&+(1-\mu^{s*}_{k,opt}(n+1,h,a^{u*}_{k,opt}(n,h,a)))c^{u*}_{k,opt}(n+1,h,a^{u*}_{k,opt}(n,h,a))^{-\sigma}\Big]^{-\frac{1}{\sigma}}
\end{aligned} \tag{B.15}$$

Finally, solving the envelope condition (B.10) for search effort μ_k^s yields the first-order condition for search effort for searching workers without capital loss

$$\mu_{k,opt}^s = \psi'^{-1}\Big(V_k^u(n,h,a) - V_k^e(n,h,a)\Big) \tag{B.16}$$

and envelope condition (B.11) yields the first-order condition for search effort of searching workers with human capital loss

$$\mu_{k,opt}^{s*} = \psi'^{-1}\Big(V_k^{u*}(n,h,a) - V_k^e(n,\kappa_k(n,h),a)\Big) \tag{B.17}$$

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.13)–(B.17)) 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 $C_k^u(n,h,a)$ and $C_k^{u*}(n,h,a)$ denote the same quantity for unemployed workers without human capital loss and with human capital loss, respectively. Given the optimal policies derived above, these present value cost functions can then be expressed recursively by

$$\begin{aligned} C_k^e(n,h,a) =& -\tau_k(n,h) \\ &+\beta(1-\delta_{k,n})C_k^e(n+1,h+1,a_{k,opt}^e(n,h,a)) \\ &+\beta\delta_{k,n}\mu_{k,opt}^s(n+1,h+1,a_{k,opt}^e(n,e,a))C_k^e(n+1,h+1,a_{k,opt}^e(n,h,a)) \\ &+\beta\delta_{k,n}[1-\mu_{k,opt}^s(n+1,h+1,a_{k,opt}^e(n,e,a))]C_k^u(n+1,h+1,a_{k,opt}^e(n,h,a)) \end{aligned} \tag{B.18}$$

$$\begin{aligned} C_k^u(n,h,a) =& \rho_k(n,h) \\ &+\beta(1-\gamma_k)\mu_{k,opt}^s(n+1,h,a_{k,opt}^u(n,h,a))C_k^e(n+1,\kappa_k(n,h),a_{k,opt}^u(n,e,a))) \\ &+\beta(1-\gamma_k)[1-\mu_{k,opt}^s(n+1,h,a_{k,opt}^u(n,h,a))]C_k^u(n+1,h,a_{k,opt}^u(n,h,a)) \\ &+\beta\gamma_k\mu_{k,opt}^{s*}(n+1,h,a_{k,opt}^u(n,h,a))C_k^e(n+1,\kappa_k(n,h),a_{k,opt}^u(n,e,a))) \\ &+\beta\gamma_k[1-\mu_{k,opt}^{s*}(n+1,h,a_{k,opt}^u(n,h,a))]C_k^{u*}(n+1,h,a_{k,opt}^u(n,h,a)) \end{aligned} \tag{B.19}$$

$$
\begin{aligned}
C_k^{u*}(n,h,a) =& \rho_k(n,h) \\
&+ \beta\mu_{k,opt}^{s*}(n+1,h,a_{k,opt}^{u*}(n,h,a))C_k^e(n+1,\kappa_k(n,h),a_{k,opt}^{u*}(n,e,a))) \\
&+ \beta[1-\mu_{k,opt}^{s*}(n+1,h,a_{k,opt}^{u*}(n,h,a))]C_k^{u*}(n+1,h,a_{k,opt}^{u*}(n,h,a))
\end{aligned}
\tag{B.20}
$$

In retirement, workers of all types receive pension benefits π for all remaining periods of life, thus the net present value of cost to the government at the first period of retirement is given by

$$
C_k^e(\bar{n}_w+1,h,a) = C_k^u(\bar{n}_w+1,h,a) = C_k^{u*}(\bar{n}_w+1,h,a) = \frac{1-\beta^{\bar{n}_r}}{1-\beta}\pi \tag{B.21}
$$

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

$$
\sum_{k\in K}\chi_k C_k^u(0,0,0) = 0 \tag{B.22}
$$

For a given UI policy choice, the model is solved by (i) guessing equilibrium parameters of the income tax function (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.3 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, recall that $V_k(n,h,a)$ denotes the present value of total utility for a worker of type k, age n, human capital level h, and asset holdings a, and for a given set of policy functions for consumption and search effort. Denote by $U_k(n,h,a)$ and $L_k(n,h,a)$ the present values of consumption utility and leisure utility, respectively, for the same worker and the same set of policies. Now, consider a worker 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 $\tilde{U}_k(\theta)$. Note that, by definition, $\tilde{U}_k(1) = U_k^s(0,0,0)$. 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 $\tilde{U}_k(\theta) = \theta^{1-\sigma}\tilde{U}_k^s(1) = \theta^{1-\sigma}U_k^s(0,0,0)$.

Now, let $V_{k,base}^s(0,0,0)$, $U_{k,base}^s(0,0,0)$, $L_{k,base}^s(0,0,0)$, and $\tilde{U}_{k,base}(\theta)$ 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 $\tilde{V}_k^s(0,0,0)$ be NPV of total utility at entry of an alternative scenario. The multiplier θ for this alternative scenario is then defined by the condition

$$\tilde{V}_k^s(0,0,0) = \tilde{U}_{k,base}(\theta) + L_{k,base}^s(0,0,0) = \theta^{1-\sigma}U_{k,base}^s(0,0,0) + L_{k,base}^s(0,0,0) \tag{B.23}$$

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

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

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

$$CE(\Delta W_k) = \left[\frac{\Delta W_k}{U_{k,base}^s(0,0,0)} + 1\right]^{\frac{1}{1-\sigma}} - 1 \tag{B.24}$$

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

$$\{\{c_{k,opt}^e(n,e,a), c_{k,opt}^u(n,e,a), c_{k,opt}^{u*}(n,e,a), \mu_{k,opt}^s(n,e,a), \mu_{k,opt}^{s*}(n,e,a)\}_{n=0}^{\bar{n}_w}\}_{k\in K} \tag{B.25}$$

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

$$\{\{a^e_{k,opt}(n,e,a), a^u_{k,opt}(n,e,a), a^{u*}_{k,opt}(n,e,a)\}_{n=0}^{\bar{n}_w}\}_{k\in K} \tag{B.26}$$

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

$$\begin{aligned} U^e_k(n,e,a) = u(c^e_{k,opt}(n,e,a)) + \beta(1-\delta_{k,n})U^e_k(n+1,e+1,a^e_{k,opt}(n,e,a)) \\ + \beta\delta_{k,n}U^s_k(n+1,e+1,a^e_{k,opt}(n,e,a)) \end{aligned} \tag{B.27}$$

$$\begin{aligned} U^u_k(n,e,a) = u(c^u_{k,opt}(n,e,a)) + \beta(1-\gamma_k)U^s_k(n+1,e,a^u_{k,opt}(n,e,a)) \\ + \beta\gamma k U^{s*}_k(n+1,e,a^u_{k,opt}(n,e,a)) \end{aligned} \tag{B.28}$$

$$U^{u*}_k(n,e,a) = u(c^{u*}_{k,opt}(n,e,a)) + \beta U^{s*}_k(n+1,e,a^{u*}_{k,opt}(n,e,a)) \tag{B.29}$$

$$U^s_k(n,e,a) = \mu^s_{k,opt}(n,e,a)U^e_k(n,e,a) + [1-\mu^s_{k,opt}(n,e,a)]U^u_k(n,e,a) \tag{B.30}$$

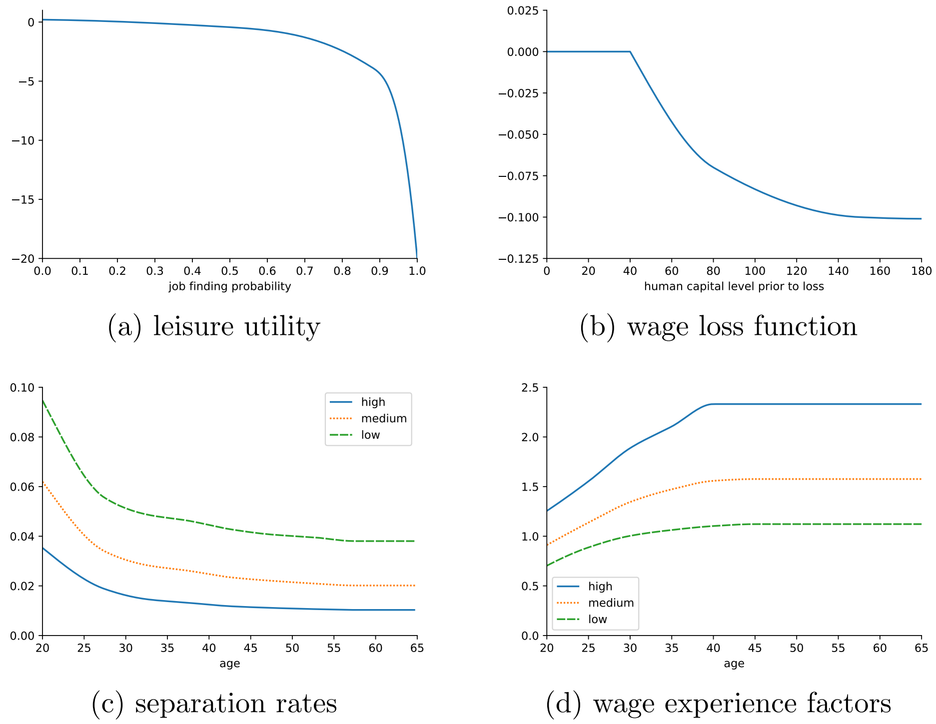
$$U^{s*}_k(n,e,a) = \mu^{s*}_{k,opt}(n,e,a)U^e_k(n,\kappa_{k,n}(h),a) + [1-\mu^{s*}_{k,opt}(n,e,a)]U^{u*}_k(n,e,a) \tag{B.31}$$

Since utility is entirely generated through consumption in retirement, we have $U^e_k(\bar{n}_w + 1,e,a) = U^u_k(\bar{n}_w+1,e,a) = U^{u*}_k(\bar{n}_w+1,e,a) = \frac{1-\beta^{\bar{n}_r}}{1-\beta}u(c^r_k(e,a))$, where $c^r_k(e,a) = \pi_k + \frac{ra}{1-\beta^{\bar{n}r}}$. Solving backwards then yields $U^s_{k,base}(0,0,0)$, which can in turn be used to calculate consumption equivalents to welfare gains relative to the baseline scenario.

C Calibrations for policy experiments

C.1 Baseline calibration

Figure C.1 depicts the calibrated functions for implicit leisure utility, human capital loss factors, separation rates and wage-experience factors.



(a) leisure utility

(b) wage loss function

(c) separation rates

(d) wage experience factors

Figure C.1: Calibrated functions leisure utility, wage loss factors, separation probabilities and wage-experience-factor

Notes: Panels (a) and (b) depict calibrated leisure utility and wage loss function, respectively. These are common for all types. Panels (c) and (d) depict calibrated separation rates and wage experience factors for workers with high type (solid blue line), medium type (dotted orange line), and low type (dashed green line).

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	Risk aversion coefficient		2.0	
$\psi(\mu)$	Leisure utility function at search intensity			
	$\mu = \{0.00, 0.25, 0.47, 0.75, 1.00\}$		$\{0.00, -0.10, -0.34, -1.88, -36.81\}$	
χ_k	Type share of population	0.31	0.58	0.11
$w_k(e)$	Wage at human capital level			
	$h = 0$	0.70	0.91	1.25
	$h = 20$	0.89	1.14	1.55
	$h = 40$	1.00	1.34	1.89
	$h = 60$	1.06	1.47	2.11
	$h = 80$	1.10	1.56	2.33
	$h = 100$	1.12	1.58	2.33
	$h = 120$	1.12	1.58	2.33
	$h = 140$	1.12	1.58	2.33
	$h = 160$	1.12	1.58	2.33
	$h = 180$	1.12	1.58	2.33
γ_k	Human capital loss probability	0.4	0.4	0.4
$\bar{\kappa}$	Human capital loss factor at age			
	$n = \{0, 40, 80, 160, 180\}$		$\{1.00, 1.00, 0.93, 0.90, 0.90\}$	
$\delta_{k,n}$	Separation rate at age			
	$n = 10$	0.079	0.038	0.021
	$n = 30$	0.063	0.033	0.013
	$n = 50$	0.058	0.030	0.012
	$n = 70$	0.055	0.028	0.012
	$n = 90$	0.050	0.026	0.013
	$n = 110$	0.048	0.025	0.013
	$n = 130$	0.043	0.024	0.014
	$n = 150$	0.039	0.024	0.016
π	Retirement pension level		0.67	
$\underline{a}$	Borrowing constraint		-1.12	
τ	Income tax rate	0.068	0.068	0.068
$\rho_{k,n}$	UI replacement rate at age			
	$n = 0$	0.50	0.50	0.50
	$n = 20$	0.50	0.50	0.50
	$n = 40$	0.50	0.50	0.50
	$n = 60$	0.50	0.50	0.50
	$n = 80$	0.50	0.50	0.50
	$n = 100$	0.50	0.50	0.50
	$n = 120$	0.50	0.50	0.50
	$n = 140$	0.50	0.50	0.50
	$n = 160$	0.50	0.50	0.50
	$n = 179$	0.50	0.50	0.50
$\underline{b}$	UI floor		0.00	
$\bar{b}$	UI cap		inf	

Table C.1: Model parameters in the base calibration

Notes: The functions $\omega_k(h)$, $\delta_{k,n}$, $\bar{\kappa}$, and $\psi(\mu)$ are splines through values in the table.

C.2 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	Risk aversion coefficient		2.0	
$\psi(\mu)$	Leisure utility function at search intensity			
	$\mu = \{0.00, 0.25, 0.47, 0.75, 1.00\}$		$\{0.00, -0.10, -0.34, -1.88, -36.81\}$	
χ_k	Type share of population	0.31	0.58	0.11
$w_k(e)$	Wage at human capital level			
	$h = 0$	0.70	0.91	1.25
	$h = 20$	0.89	1.14	1.55
	$h = 40$	1.00	1.34	1.89
	$h = 60$	1.06	1.47	2.11
	$h = 80$	1.10	1.56	2.33
	$h = 100$	1.12	1.58	2.33
	$h = 120$	1.12	1.58	2.33
	$h = 140$	1.12	1.58	2.33
	$h = 160$	1.12	1.58	2.33
	$h = 180$	1.12	1.58	2.33
γ_k	Human capital loss probability	0.4	0.4	0.4
$\bar{\kappa}$	Human capital loss factor at age			
	$n = \{0, 40, 80, 160, 180\}$		$\{1.00, 1.00, 0.93, 0.90, 0.90\}$	
$\delta_{k,n}$	Separation rate at age			
	$n = 10$	0.079	0.038	0.021
	$n = 30$	0.063	0.033	0.013
	$n = 50$	0.058	0.030	0.012
	$n = 70$	0.055	0.028	0.012
	$n = 90$	0.050	0.026	0.013
	$n = 110$	0.048	0.025	0.013
	$n = 130$	0.043	0.024	0.014
	$n = 150$	0.039	0.024	0.016
π	Retirement pension level		0.66	
$\underline{a}$	Borrowing constraint		-1.12	
τ	Income tax rate	0.075	0.075	0.075
$\rho_{k,n}$	UI replacement rate at age			
	$n = 0$	0.81	0.81	0.81
	$n = 20$	0.77	0.77	0.77
	$n = 40$	0.68	0.68	0.68
	$n = 60$	0.54	0.54	0.54
	$n = 80$	0.34	0.34	0.34
	$n = 100$	0.21	0.21	0.21
	$n = 120$	0.11	0.11	0.11
	$n = 140$	0.09	0.09	0.09
	$n = 160$	0.13	0.13	0.13
	$n = 179$	0.23	0.23	0.23
$\underline{b}$	UI floor		0.00	
$\bar{b}$	UI cap		inf	

Table C.2: Model parameters in the calibration with age-dependent replacement rates

Notes: The functions $\omega_k(h)$, $\delta_{k,n}$, $\bar{\kappa}$, and $\psi(\mu)$ 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	Risk aversion coefficient		2.0	
$\psi(\mu)$	Leisure utility function at search intensity			
	$\mu = \{0.00, 0.25, 0.47, 0.75, 1.00\}$		$\{0.00, -0.10, -0.34, -1.88, -36.81\}$	
χ_k	Type share of population	0.31	0.58	0.11
$w_k(e)$	Wage at human capital level			
	$h = 0$	0.70	0.91	1.25
	$h = 20$	0.89	1.14	1.55
	$h = 40$	1.00	1.34	1.89
	$h = 60$	1.06	1.47	2.11
	$h = 80$	1.10	1.56	2.33
	$h = 100$	1.12	1.58	2.33
	$h = 120$	1.12	1.58	2.33
	$h = 140$	1.12	1.58	2.33
	$h = 160$	1.12	1.58	2.33
	$h = 180$	1.12	1.58	2.33
γ_k	Human capital loss probability	0.4	0.4	0.4
$\bar{\kappa}$	Human capital loss factor at age			
	$n = \{0, 40, 80, 160, 180\}$		$\{1.00, 1.00, 0.93, 0.90, 0.90\}$	
$\delta_{k,n}$	Separation rate at age			
	$n = 10$	0.079	0.038	0.021
	$n = 30$	0.063	0.033	0.013
	$n = 50$	0.058	0.030	0.012
	$n = 70$	0.055	0.028	0.012
	$n = 90$	0.050	0.026	0.013
	$n = 110$	0.048	0.025	0.013
	$n = 130$	0.043	0.024	0.014
	$n = 150$	0.039	0.024	0.016
π	Retirement pension level		0.66	
$\underline{a}$	Borrowing constraint		-1.12	
τ	Income tax rate	0.076	0.076	0.076
$\rho_{k,n}$	UI replacement rate at age			
	$n = 0$	1.20	0.90	0.58
	$n = 20$	0.99	0.80	0.56
	$n = 40$	0.83	0.68	0.50
	$n = 60$	0.75	0.52	0.35
	$n = 80$	0.69	0.34	0.08
	$n = 100$	0.65	0.24	0.02
	$n = 120$	0.61	0.17	0.02
	$n = 140$	0.57	0.15	0.02
	$n = 160$	0.52	0.16	0.02
	$n = 179$	0.45	0.17	0.09
$\underline{b}$	UI floor		0.00	
$\bar{b}$	UI cap		inf	

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

Notes: The functions $\omega_k(h)$, $\delta_{k,n}$, $\bar{\kappa}$, and $\psi(\mu)$ 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	Risk aversion coefficient		2.0	
$\psi(\mu)$	Leisure utility function at search intensity			
	$\mu = \{0.00, 0.25, 0.47, 0.75, 1.00\}$		$\{0.00, -0.10, -0.34, -1.88, -36.81\}$	
χ_k	Type share of population	0.31	0.58	0.11
$w_k(e)$	Wage at human capital level			
	$h = 0$	0.70	0.91	1.25
	$h = 20$	0.89	1.14	1.55
	$h = 40$	1.00	1.34	1.89
	$h = 60$	1.06	1.47	2.11
	$h = 80$	1.10	1.56	2.33
	$h = 100$	1.12	1.58	2.33
	$h = 120$	1.12	1.58	2.33
	$h = 140$	1.12	1.58	2.33
	$h = 160$	1.12	1.58	2.33
	$h = 180$	1.12	1.58	2.33
γ_k	Human capital loss probability	0.4	0.4	0.4
$\bar{\kappa}$	Human capital loss factor at age			
	$n = \{0, 40, 80, 160, 180\}$		$\{1.00, 1.00, 0.93, 0.90, 0.90\}$	
$\delta_{k,n}$	Separation rate at age			
	$n = 10$	0.079	0.038	0.021
	$n = 30$	0.063	0.033	0.013
	$n = 50$	0.058	0.030	0.012
	$n = 70$	0.055	0.028	0.012
	$n = 90$	0.050	0.026	0.013
	$n = 110$	0.048	0.025	0.013
	$n = 130$	0.043	0.024	0.014
	$n = 150$	0.039	0.024	0.016
π	Retirement pension level		0.66	
$\underline{a}$	Borrowing constraint		-1.12	
τ	Income tax rate	0.078	0.078	0.078
$\rho_{k,n}$	UI replacement rate at age			
	$n = 0$	0.96	0.96	0.96
	$n = 20$	0.96	0.96	0.96
	$n = 40$	0.96	0.96	0.96
	$n = 60$	0.96	0.96	0.96
	$n = 80$	0.96	0.96	0.96
	$n = 100$	0.96	0.96	0.96
	$n = 120$	0.96	0.96	0.96
	$n = 140$	0.96	0.96	0.96
	$n = 160$	0.96	0.96	0.96
	$n = 179$	0.96	0.96	0.96
$\underline{b}$	UI floor		0.75	
$\bar{b}$	UI cap		0.78	

Table C.4: Model parameters in the calibration with fixed replacement rates, benefit floor and benefit cap

Notes: The functions $\omega_k(h)$, $\delta_{k,n}$, $\bar{\kappa}$, and $\psi(\mu)$ 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	Risk aversion coefficient		2.0	
$\psi(\mu)$	Leisure utility function at search intensity			
	$\mu = \{0.00, 0.25, 0.47, 0.75, 1.00\}$		$\{0.00, -0.10, -0.34, -1.88, -36.81\}$	
χ_k	Type share of population	0.31	0.58	0.11
$w_k(e)$	Wage at human capital level			
	$h = 0$	0.70	0.91	1.25
	$h = 20$	0.89	1.14	1.55
	$h = 40$	1.00	1.34	1.89
	$h = 60$	1.06	1.47	2.11
	$h = 80$	1.10	1.56	2.33
	$h = 100$	1.12	1.58	2.33
	$h = 120$	1.12	1.58	2.33
	$h = 140$	1.12	1.58	2.33
	$h = 160$	1.12	1.58	2.33
	$h = 180$	1.12	1.58	2.33
γ_k	Human capital loss probability	0.4	0.4	0.4
$\bar{\kappa}$	Human capital loss factor at age			
	$n = \{0, 40, 80, 160, 180\}$		$\{1.00, 1.00, 0.93, 0.90, 0.90\}$	
$\delta_{k,n}$	Separation rate at age			
	$n = 10$	0.079	0.038	0.021
	$n = 30$	0.063	0.033	0.013
	$n = 50$	0.058	0.030	0.012
	$n = 70$	0.055	0.028	0.012
	$n = 90$	0.050	0.026	0.013
	$n = 110$	0.048	0.025	0.013
	$n = 130$	0.043	0.024	0.014
	$n = 150$	0.039	0.024	0.016
π	Retirement pension level		0.66	
$\underline{a}$	Borrowing constraint		-1.12	
τ	Income tax rate	0.066	0.072	0.075
$\rho_{k,n}$	UI replacement rate at age			
	$n = 0$	0.73	0.79	0.89
	$n = 20$	0.64	0.72	0.79
	$n = 40$	0.52	0.62	0.67
	$n = 60$	0.37	0.47	0.47
	$n = 80$	0.20	0.25	0.23
	$n = 100$	0.10	0.05	0.17
	$n = 120$	0.04	0.02	0.16
	$n = 140$	0.03	0.02	0.16
	$n = 160$	0.15	0.02	0.23
	$n = 179$	0.36	0.21	0.35
$\underline{b}$	UI floor		0.00	
$\bar{b}$	UI cap		inf	

Table C.5: Model parameters in the calibration with age-and-type-dependent replacement rates and UI budget by type fixed to baseline levels

Notes: The functions $\omega_k(h)$, $\delta_{k,n}$, $\bar{\kappa}$, and $\psi(\mu)$ 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.