EIEF WORKING PAPER SERIES

EINAUDI INSTITUTE FOR ECONOMICS AND FINANCE

EIEF Working Paper 11/14
September 2014

Optimal Life Cycle Unemployment Insurance

by

Claudio Michelacci
(EIEF and CEPR)
Hernan Ruffo
(UTDT)

Optimal Life Cycle Unemployment Insurance

Claudio Michelacci
EIEF and CEPR

Hernán Ruffo*
UTDT

September 17, 2014

Abstract

We argue that US welfare would rise if unemployment insurance were increased for younger and decreased for older workers. This is because the young tend to lack the means to smooth consumption during unemployment and want jobs to accumulate high-return human capital. So unemployment insurance is most valuable to them, while moral hazard is mild. By calibrating a life cycle model with unemployment risk and endogenous search effort, we find that allowing unemployment replacement rates to decline with age yields sizeable welfare gains to US workers.

*Michelacci: EIEF, Postal address: EIEF, Via Sallustiana, 62, 00187 Roma, Italy. E-mail: c.michelacci1968@gmail.com. Ruffo: UTDT, Postal address: UTDT, Avenida Figueroa Alcorta 7350, C1428BCW, Buenos Aires, Argentina. E-mail: hruffo@utdt.edu. The research reported in the paper is not the result of any for-pay consulting relationship. We are indebted to four anonymous referees whose insightful suggestions have contributed to significantly improving the paper. We would also like to thank Raj Chetty, Dmytro Hryshko, Maria Jose Luengo-Prado, and Corina Mommaerts for kindly making their data available and promptly answering questions about them. Finally we are very grateful to seminar participants at all the institutions and conferences where this paper has been presented. Hernán Ruffo acknowledges some support from FONCyT (PICT/2588-2010). Claudio Michelacci acknowledges the financial support of the European Research Council (ERC Advanced Grant 293692).

1 Introduction

The thesis that government transfers and taxes should be conditional on observable, immutable indicators of skills goes back at least to Akerlof (1978). More recently Kremer (2001), Erosa and Gervais (2002), Gervais (2004), Farhi and Werning (2013), Gorry and Oberfield (2012), Mirrlees et al. (2010), and Weinzierl (2011) have also called for setting labor and capital income tax rates on the basis of age, for an efficient tax system. In principle, this logic also applies to unemployment insurance and other labor market institutions. Such key economic variables as wages, wealth, consumption, and unemployment duration vary over the life cycle, which suggests that workers' incentive to search for a job and their ability to cope with unemployment risk vary accordingly. Here we argue that, given present US labor market institutions, overall welfare would be improved if unemployment insurance were increased for relatively young workers (in their mid-twenties and early thirties) and decreased for older workers (in their forties and mid-fifties).

The idea is that unemployment insurance is most valuable to young workers—because they typically have little means to smooth consumption during a spell of unemployment—while the costs of the implicit problem of moral hazard are minor—because young workers want jobs anyway to improve life-time career prospects, and build up human capital whose marginal return is high when young. The underlying intuition emerges from a simple formula. Consider a government that uses one dollar to finance an increase in unemployment benefits b_n for a given age group n. Denote by μ_n the number of unemployed workers in the age group, by c_{un} their consumption level when unemployed and by $u'(c_{un})$ their marginal utility of consumption. If all currently unemployed workers receive one unit of money, welfare would increase by $\mu_n u'(c_{un})$. But standard moral hazard problems imply that more generous transfers drive up unemployment, and each unemployed worker receives benefits b_n. So a marginal increase in transfers yields only $1/[\mu_n + b_n d\mu_n/db_n] = 1/[\mu_n(1+\eta_n)]$ units of income to a currently unemployed worker, where η_n is the elasticity of group n unemployment to the corresponding unemployment benefits. By multiplying the two terms we find the following welfare gains from the marginal change in government transfers:

$$\varrho_n = \frac{u'(c_{un})}{1+\eta_n}. \tag{1}$$

Intuitively the numerator gives the marginal value of the increase in Unemployment Insurance, the denominator the incentive costs of moral hazard. Generally a

revenue-neutral change in unemployment insurance that raises benefits for a given age group n and lowers them for another age group m is welfare improving whenever $\varrho_n > \varrho_m$, which can be used to identify possible gains from redistributing unemployment insurance over the life cycle. This logic focuses on redistributing a given amount of government income across unemployed workers of different age. But government income is typically financed through tax revenue, which is affected by the age profile of unemployment benefits through its effects on employment and human capital accumulation. In the paper we discuss how to incorporate this and other effects into (1) and also study the relative quantitative importance of tax effects, which have been greatly emphasized by the public finance literature, see for example Mirrlees et al. (2010).

We start documenting how ϱ_n in (1) varies across age groups. First we use data from the Panel Study of Income Dynamics (PSID) and show that the consumption of unemployed workers is strictly increasing in age. Roughly speaking, an unemployed worker in his thirties consumes 30 per cent less than one in his fifties. We also use data from the Current Population Survey (CPS) and from the Survey of Income and Program Participation (SIPP) to analyze how the level of unemployment in different age groups responds to changes in unemployment benefits. As in Chetty (2008), we exploit changes in the level of benefits within US states over time. We find that while the elasticity of unemployment to benefits is small and statistically insignificant for workers in their mid-twenties and early thirties, it is positive and significant for workers in their mid-forties and fifties. Meyer and Mok (2007) find similar results. Gritz and MaCurdy (1992) also show that changes in benefits have insignificant effects on the level of unemployment among young workers. This evidence indicates that providing additional insurance to young worker is highly valuable, while the incentive costs of moral hazard are small, which implies that ϱ_n is unambiguously larger for younger than for older workers.

The data also offer more direct evidence of the high value and low moral hazard of unemployment insurance for young workers. We show that consumption losses upon unemployment are greater for younger than for older workers, and that the job search behavior of young workers is strongly responsive to the provision of severance payments at the time of job loss. This indicates that young unemployed workers have little ability to smooth consumption and require more liquidity and insurance. Chetty (2008) observes that the effect of benefits on the unemployment of wealthy workers—who arguably have greater ability to smooth

consumption—measures the severity of the moral hazard problem. We find that the unemployment duration of older workers with substantial assets is affected powerfully by benefits, while that of young wealthy workers is relatively insensitive to benefits. This suggests that the moral hazard problem is severe among older workers while it is relatively insignificant among younger workers. This squares with the idea that young workers want jobs not only to increase their current income but also to acquire labor market skills and so improve career prospects and lifetime income.

To study the magnitude of the potential welfare gains of age-dependent unemployment insurance, we consider a conventional life cycle model with decreasing returns to labor market experience and ongoing unemployment risk. Workers are born with zero human capital and no assets and can save in a riskless bond. When employed, they accumulate human capital, receive wages and pay income taxes to finance unemployment insurance and retirement pensions. Workers may lose their job and suffer a depreciation of their human capital. When unemployed they choose the intensiveness of job search. During unemployment they receive benefits that are a constant fraction of past wages. The model is calibrated to match US labor market institutions and other key features of the workers' life cycle.

We optimally choose age-dependent replacement rates and/or income tax rates to maximize the worker's initial expected utility.[1] We find that under the optimal age-dependent policy, replacement rates would rise from 50 per cent as now to around 80 percent for workers in their mid-twenties and 60 per cent for those in their thirties. Workers in their forties and fifties, instead, would get benefits of less than 10 percent of their last wage. When allowing for just age-dependent replacement rates, the welfare gain is equivalent to almost 1 percent of lifetime consumption. When combining age-dependent unemployment insurance with age-dependent taxes, the gain increases to more than 3 percent of lifetime consumption.

To analyze whether age-dependent policies would use up a significant part of the potential gains inherent in current US labor market institutions, we consider the problem of an agency that must optimally choose benefits, taxes, and pensions as a function of the worker's entire history. The agency can observe workers' assets as well as search effort, so unemployment insurance creates no moral hazard. Al-

[1] An alternative would be to make replacement rates and taxes conditional on current assets, not age. Although this would distort saving incentives and is in principle inferior to age-dependent policies, it could still yield substantial gains in welfare. This point is made by Conesa, Kitao and Krueger (2009), Rendahl (2012), and Koehne and Kuhn (2014).

though age-dependent policies can reproduce the solution of the optimal program only imperfectly, we surprisingly find that making both unemployment insurance and taxes age-dependent yields 90 percent of the welfare gains obtained under the optimal program. Around a quarter of these gains are due to age dependent unemployment benefits.

Further relation to the literature Using diverse methodologies, several authors have argued that the level of unemployment benefits is close to optimal in the US, see for example Davidson and Woodbury (1997), Shimer and Werning (2007), Pavoni (2007), and Chetty (2008). Our results show that, while they are optimal on average, sizable welfare gains are still possible by redistributing unemployment benefits over the life cycle—increasing them for the young and decreasing them for the old.

This paper relates to the literature that since Hopenhayn and Nicolini (1997) has analyzed the optimal design of labor market institutions, including Pavoni and Violante (2007), Shimer and Werning (2008), Pavoni (2009), Rendahl (2012), and Pavoni, Setty and Violante (2010). These works typically posit an initially unemployed worker who becomes permanently employed upon finding his first job. Except for Hopenhayn and Nicolini (2009), they neglect recurrent spells of unemployment. This literature has also abstracted from life cycle effects due to non-linear returns to labor market experience and asset accumulation which constitute the main focus of this paper.

Baily (1978) and Chetty (2006) have proposed simple formulas to evaluate whether unemployment benefits are on average optimal. Our formula ϱ_n is similar, but focuses on possible gains from redistributing benefits over the life-cycle or more generally across any groups of workers classified by observable, immutable skill characteristics including gender or race. The formula ϱ_n works exactly in the stylized model of Section 2. But the quantitative analysis also indicates that the key forces highlighted in ϱ_n dominate in today's US labor market institutions. To be sure, the simple formula ϱ_n neglects the effects of age-specific changes in benefits on tax revenue, on worker human capital, and on unemployment among age groups not directly targeted by the policy change. And we show that these considerations lead to an extended redistribution formula that works exactly in the quantitative model. But although the simple and extended formula could differ, we find that, in our laboratory economy, they exhibit a remarkably similar age profile.

Shimer and Werning (2007) and Chetty (2008) have criticized Baily's formula for relying on highly controversial preference parameters. Our own formula is less subject to their criticism in that its ability to identify redistribution gains just relies on signing the relative magnitude of ϱ_n across skill groups. This is often possible just by comparing unemployment elasticities and consumption levels when unemployed across skill groups, without having to specify any preference parameter.

Chéron, Hairault and Langot (2012, 2011) have studied the role of age-dependent labor market policies in a search model with finitely lived workers a la Mortensen and Pissarides (1994). Our paper is obviously related, but with some important differences. Chéron, Hairault and Langot (2012, 2011) emphasize the demand side of the labor market and the role of age-dependent policies in solving the conventional search inefficiencies in vacancy creation typically found in random search models; see Pissarides (2000) for an introduction to this class of models. Search inefficiencies naturally vanish in extended versions of the search model in which firms post wage contracts, workers observe them and direct their search accordingly; see for example Moen (1997), Acemoglu and Shimer (2001), Shimer (2005) and more recently Menzio and Shi (2011). Here we emphasize labor supply effects and the variation over the life cycle in the trade-off between the gains from unemployment insurance and the incentive costs of moral hazard.

Section 2 uses a stylized life cycle model to discuss the formula in (1) and its extension. Section 3 presents preliminary evidence. Section 4 describes our laboratory economy. Section 5 solves for the first best. Section 6 studies age-dependent policies, Section 7 discusses robustness and Section 8 concludes. The Online Appendix provides the details on data and computation.

2 A stylized life cycle model

We present a simple stylized life cycle model in which our simple formula holds exactly. We then extend it to incorporate additional effects that lead to an extended formula. We later show that these formulas work well in a more conventional life cycle model more suitable for quantitative analysis.

2.1 The worker's problem

In this stylized model workers live for six periods ($i = 1{-}6$). They are young, $n = y$, during the first three periods ($i = 1{-}3$), and old, $n = o$, during the

last three ($i = 4{-}6$). The sole risk is unemployment. Workers are employed with probability one in all periods except in period two and five, when they must search for a job. This characterizes the fact that unemployment risk is recurrent, it affects both young and old, and it has transitory effects. Unemployment is endogenous due to search intensity decisions. Search intensity reduces both the probability of unemployment and one's leisure time. We assume that a worker who is unemployed with probability μ at the end of period 2 or 5 enjoys utility from leisure equal to $\psi(\mu)$, with $\psi'(\mu) > 0$ and $\psi''(\mu) < 0$. Workers initially have no wealth. They cannot borrow but can save via a risk-free bond that pays a constant interest rate r equal to their subjective discount rate. So the workers' subjective discount factor is equal to $\beta = 1/(1 + r)$. Following well established evidence from wage regressions, we assume that wages when young w_i ($i = 1{-}3$) increase over time, while wages when old w_i ($i = 4{-}6$) are flat and equal to $\bar{w}$, with $w_1 < w_2 < w_3 < \bar{w}$. If unemployed at age $n = y, o$ (end of period 2 or 5) workers receive unemployment benefits b_n. Consumption utility in a period is $u(c)$.

We assume that consumption is equal to income for young workers: a young worker expects future increases in labor income and would like to borrow to smooth consumption but cannot owing to the borrowing constraint.[2] This simplifying assumption implies that old workers' decisions are not affected by their employment history, which guarantees that changes in benefits when young (old) do not affect unemployment when old (young). As is noted in Section 2.3, this separability property is required for the formula to hold exactly. Separability implies that the worker's initial expected utility can be expressed as equal to

$$W(b_y, b_o) \equiv Y(b_y) + O(b_o) \tag{2}$$

where $Y(b_y) = \max_\mu \tilde{Y}(b_y, \mu)$ and $O(b_o) = \max_\mu \tilde{O}(b_o, \mu)$ are the sum of discounted utilities when young ($i = 1$–3) and when old ($i = 4$–6), respectively. In the expression

$$\tilde{Y}(b_y, \mu) \equiv u(w_1) + \beta\left[\psi(\mu) + \mu u(b_y) + (1 - \mu)u(w_2)\right] + \beta^2 u(w_3), \tag{3}$$

is the sum of utilities obtained by young workers for a given unemployment prob-

[2]Even if wages are growing and the interest rate is equal to the worker's subjective discount rate, young workers might want to accumulate some precautionary savings to insure against the risk of unemployment in period 2. Here we assume that consumption smoothing dominates the precautionary savings motive so that $u'(w_1) \geq \mu_y u'(b_y) + (1 - \mu_y)u'(w_2)$ where μ_y is the equilibrium unemployment probability in period 2.

ability μ in period 2, while

$$\tilde{O}(b_o, \mu) \equiv \beta^3 \max_{a \geq 0} \left\{ u(\bar{w} - a) + \beta\psi(\mu) + \beta\mu \left[u\left(b_o + \frac{a}{\beta}\right) + \beta u(\bar{w}) \right] \right. \quad (4)$$

$$\left. + \beta(1-\mu)(1+\beta)\, u\left(\bar{w} + \frac{a}{1+\beta}\right) \right\} \quad (5)$$

is the analogous sum for older workers when the unemployment probability μ in period 5 is taken as given. In (5), a denotes the precautionary savings that the household accumulates in period 4 to finance consumption during unemployment in period 5, which occurs with endogenously determined probability μ. If instead the worker remains employed, a serves to increase consumption equally in periods 5 and 6. This accounts for the last term in (5).[3]

2.2 The government's problem

As is standard in the optimal unemployment insurance literature—see for example Hopenhayn and Nicolini (1997) and Shimer and Werning (2007, 2008)—we assume that government interventions are actuarially fair so that the present value of UI transfers is equal to the present value of some exogenous government income T, which we later endogenize. The government chooses b_n, $n = y, o$, so as to maximize workers' expected utility W in (2) subject to the budget constraint

$$\beta_y \mu_y(b_y) b_y + \beta_o \mu_o(b_o) b_o = T \quad (6)$$

where $\beta_y = \beta$ and $\beta_o = \beta^4$ are the discount factors, while the functions $\mu_y(b_y)$ and $\mu_o(b_o)$ determine the age-specific unemployment probabilities μ_y and μ_o given the age-specific benefit levels b_y and b_o, respectively. Given (3) and (5) these functions are implicitly defined by the conditions $\mu_y = \arg_\mu \max \tilde{Y}(b_y, \mu)$ and $\mu_o = \arg_\mu \max \tilde{O}(b_o, \mu)$, respectively. The Lagrangian of the problem reads as $\mathrm{L}(\mathrm{b}_y, b_o, \lambda) = Y(b_y) + O(b_o) + \lambda\left[T - \beta_y \mu_y(b_y) b_y - \beta_o \mu_o(b_o) b_o\right]$where λ is the Lagrange multiplier of the budget constraint in (6). Taking the first order condition with respect to b_n, $n = y, o$, and using the envelope theorem, we immediately find that it is optimal to increase b_n if

$$\beta_n \mu_n u'(c_{un}) > \lambda \beta_n \mu_n + \lambda \beta_n \frac{d\mu_n}{db_n} b_n \quad (7)$$

[3] In equilibrium a will always be in the interval $(0, \bar{w} - b_o)$, so the constraint $a \geq 0$ will be slack, while the borrowing constraint will be binding in period 5 if the worker is unemployed.

where c_{un} denotes consumption when unemployed at age n. Rearranging, the above condition is equivalent to

$$\varrho_n \equiv \frac{u'(c_{un})}{1+\eta_n} > \lambda \tag{8}$$

where $\eta_n \equiv \frac{d \ln \mu_n}{d \ln b_n}$ is the elasticity of unemployment to benefits of age group n. The ratio on the left-hand side is the net welfare gain of marginally increasing government transfers to unemployed workers of age n: the numerator measures the value of the marginal increase in UI benefits, the denominator the cost of the induced increase in unemployment. Optimal life cycle unemployment insurance requires $\varrho_n = \lambda$ for any age group n. Generally there are welfare gains from increasing transfers to young unemployed workers at the expense of the old whenever

$$\varrho_y > \varrho_o. \tag{9}$$

Interestingly, the comparison does not require evaluating consumption losses upon displacement. This is simply because the government compares the gains of increasing transfers to unemployed workers of different ages whose marginal value is measured by their state contingent marginal utility of consumption. The derivation that leads to (9) is hardly affected in several extensions of the baseline model. In particular the formula remains valid in cases of:

1. *Differences in workers demand and/or supply* The utility from leisure is age-specific, $\psi_n(\mu)$, $n = y, o$, with $\psi_n'(\mu) > 0$ and $\psi_n''(\mu) < 0$. This accounts for possible differences in the demand for workers of different ages as well as in their labor supply, both of which can affect job-finding probabilities.[4]

2. *Varying job loss probabilities* Workers search for a job in periods 2 and 5 with age-specific probability δ_n, $n = y, o$ (in the baseline model $\delta_y = \delta_o = 1$), to account of the fact that the risk of job loss varies over the life cycle.

3. *Other income* Workers have access to other sources of income y_n (say, the spouse's earnings), whose relative importance varies over the life cycle.

[4] To see why an age-dependent Ψ function subsumes age effects in both labor demand and supply, assume that, as in standard search models (Pissarides, 2000), the unemployment probability of workers of age n is a decreasing function of both their search effort s and market tightness θ_n for that age group of workers, so that $\mu = \mu(s, \theta_n)$. Age-specific differences in demand are reflected in θ_n. The disutility of search effort is $\widetilde{\Psi}_n(s)$, which is age-specific to characterize age differences in labor supply. We can then invert the function μ to express search effort as function of μ and θ_n so as to obtain the simple formulation in the text based on $\Psi_n(\mu) \equiv \widetilde{\Psi}_n(\mu^{-1}(\mu, \theta_n))$.

4. *Changing household size* The household is represented by a simple unitary model with consumption utility $m_n u\left(C/m_n\right)$, where m_n denotes household size when household head has age n, while C denotes household total consumption expenditures. This takes into account that household size changes over the life cycle with marriage, the birth of children and their growing up and leaving home. Due again to the envelope theorem, the marginal value of a unitary increase in benefits is $u'\left(C/m_n\right)$. This implies that c_{un} in (8) has to be interpreted as per capita household consumption when a household head of age n is unemployed.

5. *Tax effects* The UI program is financed through income taxes equal to a (possibly) age-specific proportion τ_n, $n = y, o$, of net wages w_i, i =1-6, so that

$$T \equiv T(b_y, b_o) = \overline{T} - \beta_y \mu_y(b_y)\tau_y w_2 - \beta_o \mu_o(b_o)\tau_o w_5.$$

Here $\overline{T} = \tau_y \sum_{i=0}^{2} \beta^i w_{i+1} + \tau_o \sum_{i=3}^{5} \beta^i w_{i+1}$ denotes the present value of tax revenue under no unemployment, while the last two terms measure the fall in tax revenue due to unemployment in period 2 and 5. By applying the same logic as in (7), we then obtain the following slightly modified version of ϱ_n: $\widehat{\varrho}_n = \frac{u'(c_{un})}{1+\eta_n\left(1+\frac{\tau_n}{\rho_n}\right)}$where $\rho_y \equiv \frac{b_y}{w_2}$ and $\rho_o \equiv \frac{b_o}{w_5}$ denotes the UI replacement rate at age $n = y$ and $n = o$, respectively. $\widehat{\varrho}_n$ differs from ϱ_n in (8) just because of the quantity $\eta_n \frac{\tau_n}{\rho_n}$ in the denominator of $\widehat{\varrho}_n$, which measures the fall in taxes due to the age-specific increase in benefits. When the tax system has no age-specific features (ρ_n and τ_n are both independent of n), $\widehat{\varrho}_n$ and ϱ_n have the same age profile. But in practice, the ratio $\frac{\tau_n}{\rho_n}$ is increasing in n, since wages rise with age and higher wages make τ_n higher—due to the progressivity of the tax system— and ρ_n lower—since UI replacement rates are typically constant up to a maximum. Since this effect makes it more likely that $\widehat{\varrho}_n$ is decreasing in n, $\widehat{\varrho}_y > \widehat{\varrho}_o$ is implied by the condition $\varrho_y > \varrho_o$—at least provided that $\eta_o \geq \eta_y$, which, as we show in Section 3, is the empirically relevant case. This simply means that the inequality in (9) based on ϱ_n indicates the existence of welfare gains from redistributing UI benefits from the old to the young even in the presence of tax effects.[5]

[5]Of course with different tax effects, it could well be that $\widehat{\varrho}_n$ is more useful than ϱ_n for identifying welfare gains from redistribution. We thank one of the referees for this discussion.

2.3 The extended redistribution formula $\widetilde{\varrho}$

The simple redistribution formula ϱ in (8) can be modified to extend the analysis in three ways. First we allow young workers in period 1 to save. Second, we allow for a general tax revenue function $T(b_y, b_o)$, which is more in keeping with the quantitative analysis of Section 4, where tax revenue depends on workers' employment status and human capital. Third, the optimal choice of benefits is now subject to the feasibility constraint that benefits cannot fall below a minimum level $\bar{b}_n$ so that

$$b_n \geq \bar{b}_n, \quad \forall n = y, o. \tag{10}$$

In the quantitative analysis of Section 4, this minimum is set to zero.

Since young workers can save, their employment state will affect their future decisions when they get old. Generally the choices for assets and unemployment probabilities at any time i are now contingent on the history up to that time. Moreover, since asset choices are forward-looking, the equilibrium unemployment probability at a given age is function of both b_y and b_o, so we now have $\mu_y = \mu_y(b_y, b_0)$, and $\mu_o = \mu_o(b_y, b_0)$. The full analysis of the extended model is in the Online Appendix, where we show that the value of marginally increasing benefit transfers to unemployed workers of age n—i.e. the analogue of ϱ_n in (8)— is now given by

$$\widetilde{\varrho}_n = \frac{E\left[u'\left(c_{un}\right)\right] + \frac{\omega_n}{\mu_n}}{1 + \widetilde{\eta}_n - \frac{\partial T}{\partial b_n} \cdot \frac{1}{\mu_n}}. \tag{11}$$

In this expression $E\left[u'\left(c_{un}\right)\right]$ is the expected marginal utility of consumption of unemployed workers of age n, $\omega_n \geq 0$, $n = y, o$ is the current value Lagrange multiplier of the benefits feasibility constraint in (10), while

$$\widetilde{\eta}_n = \sum_{i=y,o} \frac{\partial \mu_i}{\partial b_n} \cdot \frac{\beta_i b_i}{\beta_n \mu_n} \tag{12}$$

is the modified elasticity of unemployment to account for the fact that changing benefits for a given age group n potentially affects the unemployment level of other age groups. Finally, $\frac{\partial T}{\partial b_n}$ is the partial derivative of tax revenue with respect to the change in benefits. Generally, there are welfare gains from increasing transfers to young unemployed workers at the expense of the older whenever

$$\widetilde{\varrho}_y > \widetilde{\varrho}_o. \tag{13}$$

There are four simple reasons why $\widetilde{\varrho}_n$ differs from ϱ_n.

1. *Heterogeneity in assets* Since assets depend on employment histories, unemployed workers of the same age may now have different consumption levels. This is why the expected marginal utility of consumption forms part of the numerator of (11).
2. *Unemployment cross derivatives* Since the unemployment probability at a given age is a function of the overall age profile of benefits, increasing benefits for an age group n can affect the unemployment level of any age group. Thus, the present value of total UI expenditures generally increases by $\beta_n \mu_n (1 + \widetilde{\eta}_n)$.
3. *Reduction in tax revenue* Benefits reduce government revenue T because of lower labor income, due to higher unemployment and less human capital accumulation. This cost is measured by the derivative $-\frac{\partial T}{\partial b_n}$.
4. *Positive benefits* When ω_n is positive (the constraint in (10) is binding), the government would like to decrease benefits further for unemployed workers of age n, because their consumption is inefficiently high. In the quantitative analysis of Section 4, this constraint will be binding for older workers.

Although $\widetilde{\varrho}_n$ and ϱ_n are different in general, we will see that, in the baseline calibration of the laboratory economy set out in Section 4, $\widetilde{\varrho}_n$ and ϱ_n exhibit a remarkably similar age profiles, which indicates similar welfare gains from redistributing unemployment insurance over the life cycle. Differences begin to be significant only when the optimal values for age-dependent benefits are selected. A simple interpretation is that the differences between $\widetilde{\varrho}_n$ and ϱ_n matter only when policies are close to optimal, while, under current US labor market institutions, the key forces highlighted by the simple formula in (8) dominate.

3 Some empirical evidence

We now show that in the US the elasticity of unemployment to Unemployment Insurance (UI) benefits and consumption while unemployed are both lower for young than for older workers. This indicates that inequality (9) holds both because young workers' incentives to search for a job are less strongly affected by benefits (the denominator in (8) is smaller) and because they value unemployment insurance more (the numerator is higher). We then provide more direct evidence i) that the moral hazard induced by unemployment insurance is modest for young workers, and ii) that young workers have little ability to smooth consumption during unemployment and therefore value the insurance and liquidity provided

by benefits more highly. We will use this evidence later to evaluate the quantitative properties of the model of Section 4. We start with a brief discussion of the datasets used, for full details on data construction and sample selection criteria, see the Online Appendix.

3.1 The data

Our data come from the Survey of Income and Program Participation (SIPP), the Current Population Survey (CPS), the Panel Study of Income Dynamics (PSID) and surveys collected by Mathematica on behalf of the US Department of Labor. The SIPP and Mathematica data are used for an unemployment duration analysis at individual level; the CPS to estimate the aggregate effects of benefits on unemployment; the PSID for evidence on consumption. In all cases the analysis focuses on working-age men. Sample periods vary but run roughly from the 1980's to the early 2000's. Sample selection in the SIPP and the Mathematica data is exactly as in Chetty (2008). As far as possible we apply the same criteria to the construction of the CPS and PSID samples.

We use two measures of UI benefits. One is the imputation of *individual* benefits in the SIPP data by Chetty (2008). The other is a measure of the *average* benefits received by unemployed workers of different age groups in each US state and year. The construction of this latter measure mirrors Chetty (2008) but with CPS data: we first use the March CPS survey to impute pre-unemployment wages to each unemployed worker in the sample and then gauge individual UI benefits using the calculator devised by Cullen and Gruber (2000). The resulting individual benefits are then averaged for age-groups, states and years.

Consumption in PSID is measured using either food consumption at home, which is reported directly by PSID, or total consumption expenditure for non-durables, which is imputed using the methodology of Blundell, Pistaferri and Preston (2008) as in Hryshko, Luengo-Prado and Sorensen (2010). The imputation covers both the core and the SEO sample in PSID, which gives us a more representative sample than in Blundell, Pistaferri and Preston (2008). Consumption corresponds to the average per capita weekly expenditures in the household, which, like Blundell, Pistaferri and Preston (2008), we interpret as measuring household consumption in an average week around the time of the survey week.

3.2 Elasticity of unemployment to benefits

To calculate the elasticity of unemployment to benefits for workers of different ages, we start splitting the SIPP sample into two age groups, 20-40 and 41-60. This split is justified by the fact that after age 40, the return to labor market experience substantially flattens while assets increase significantly. We show later that this is important in determining the value and the moral hazard costs of UI. For each sample, we then estimate the following semi-parametric Cox proportional-hazards regression for unemployment duration:

$$\ln h_{it} \quad = \quad \beta \ln b_{it} + \theta X_{it} + err. \tag{14}$$

where i denotes the worker, t the duration of the current unemployment spell, h_{it} the job finding probability at unemployment duration t, b_{it} the level of UI benefits, and X_{it} a set of controls including worker's age, years of education, a marital status dummy, previous job tenure, a spline in logged past wages, dummies for year, state, and unemployment duration and the interaction of benefits with unemployment duration. The effects of benefits are identified by a difference-in-differences strategy that exploits changes in unemployment benefits rules of US states over time. Table 1 reports the results for the two measures of benefits. Panel (a) shows individual benefits, panel (b) age-specific average benefits.[6] The first column of panel (a) shows the full sample estimates, which are analogous to those in Chetty (2008). Here the elasticity of the job finding probability to benefits

Table 1: Job finding elasticity to benefits, SIPP

(a) Individual UI benefits

	All	*20-40 yrs*	*41-60 yrs*
ln ben.	-.36***	-.23	-.86***
	(.11)	(.16)	(.19)
N. of spells	4529	2858	1522

(b) Age-specific average UI benefits

	All	*20-40 yrs*	*41-60 yrs*
ln ben.	-.34*	-.19	-1.36***
	(.20)	(.25)	(.46)
N. of spells	4380	2858	1522

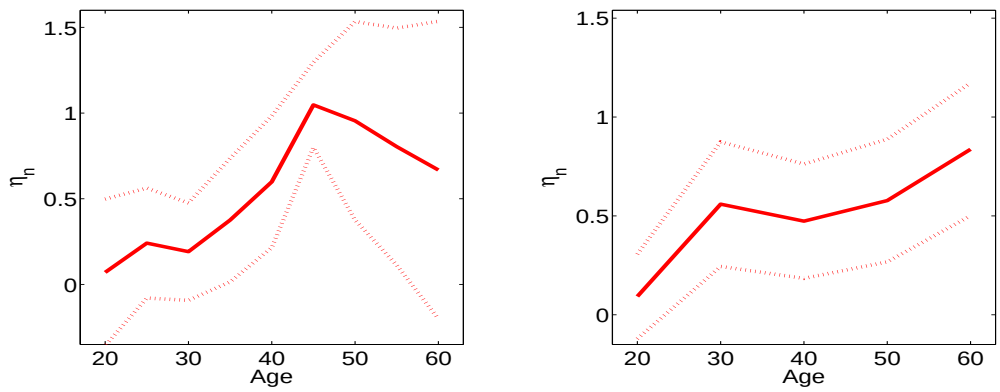
Notes: Estimates of β in the Cox regression (14) using SIPP data. In panel (a) benefits are individually imputed, in panel (b) they are age-specific state-year averages. The first column shows full sample; the second and third workers in age groups 20-40 and 41-60, respectively. Standard errors clustered by state in parenthesis. "***" indicates significance at 1%, "**" at 5%, "*" at 10%.

is very close to one third and highly significant. The results in the following two

[6]Much of the variation by age in UI replacement rates is due to the fact that wages are typically replaced by a constant percentage, usually 50%, but only up to a maximum that differs from state to state. Since wages generally increase with age, this implies that actual replacement rates are lower for older than for younger workers.

columns show that the full sample estimates in Chetty (2008) conceal substantial heterogeneity according to age. For the sample of workers aged 20-40, the effects of UI benefits on job finding are small and not statistically significant for either measure of benefits. For the sample of older workers, the estimated elasticity is instead close to 1 and strongly significant for both measures.[7]

We now split the data into finer age groups. To maintain sample size, we estimate the unemployment duration regression in (14) using nine partly overlapping samples with age differences of ten years. To measure the elasticity of unemployment to benefits, we use the relation $d\ln u/d\ln b = -(1-u)d\ln f/d\ln b$, where $d\ln f/d\ln b$ is the estimated elasticity of job finding while u and f are the sample average of the unemployment rate and the finding rate, respectively. The relation is exact if benefits affect unemployment only though the job finding rate. Panel (a) in Figure 1 reports the age profile of the resulting elasticity of unemployment based on individual benefits. The results with the age-specific average measure of



(a) Micro-evidence, SIPP data

(b) Aggregate-evidence, CPS data

Notes: Elasticity of unemployment to benefits by worker's age. Panel (a) estimates are based on (14) using SIPP data and individual benefits. Unemployment elasticities are calculated using the formula $\frac{d\ln u}{d\ln b} = -(1-u)\frac{d\ln f}{d\ln b}$, where u and f are the sample average of the unemployment rate and the finding rate, respectively. Panel (b) are estimates of β_n in (15) using US states aggregate unemployment data from CPS. Dotted lines are 90 percent confidence intervals.

Figure 1: elasticity of unemployment to benefits by age group

benefits are in Figure A1 in the Online Appendix. The dotted lines represent 90-percent confidence intervals. The elasticity of unemployment is around 20 percent

[7]We checked that these results are robust to including as controls the log of individual wealth or of net liquid assets at the time of job loss, or to using a Weibull regression for unemployment duration. We have also split the sample into three educational groups (less than high school, high school graduates, at least some college) and found similar results for the three groups.

for workers in their twenties and early thirties and nearly 100 percent for those in their mid-forties and early fifties. For workers close to retirement it tends to fall, but confidence intervals are very large, indicating imprecise estimates.

So far we have focused on how UI benefits affect job finding rates. But benefits can also affect unemployment through labor force participation or through the unemployment inflow rate, and they may have aggregate equilibrium effects not properly measured by unemployment duration regressions. To address some of these concerns, we use US states' aggregate unemployment data from CPS and the age-specific average measure of benefits to estimate the following regression:

$$\ln u_{itj} \quad = \quad \sum_n \beta_n q_j^n \ln b_{itj} + \theta X_{itj} + err. \tag{15}$$

where i stands for the state, t for the period (half and year) and j for age group, u_{tij} is the ratio of unemployment to population for age group j in state i in period t, q_j^n is a dummy variable which is equal to 1 if the observation corresponds to age group n, and b_{itj} is the imputed age-specific average benefit level deflated with the CPI. The variables X_{itj} are a set of controls, including time, state, and age-group dummies, the imputed log of average pre-unemployment wages (again deflated with the CPI), the proportion in the group of white men, of married workers, of workers with working spouse, and of unemployed workers with five different educational levels. Standard errors are clustered at the state level, since different US states are considered as partially segmented labor markets. Panel (b) of Figure 1 plots the estimated values of β_n in (15), which measure the elasticity of unemployment to benefits for workers of age n. Dotted lines are 90 percent confidence intervals. The estimated elasticities of unemployment are again increasing in age. They are very close to zero for workers in their twenties and around 0.7 for those in their fifties. Estimates are comparable to those from the unemployment duration analysis in panel (a), although they are now slightly smaller and there is no longer any evidence that the elasticity falls towards zero for workers close to retirement.[8]

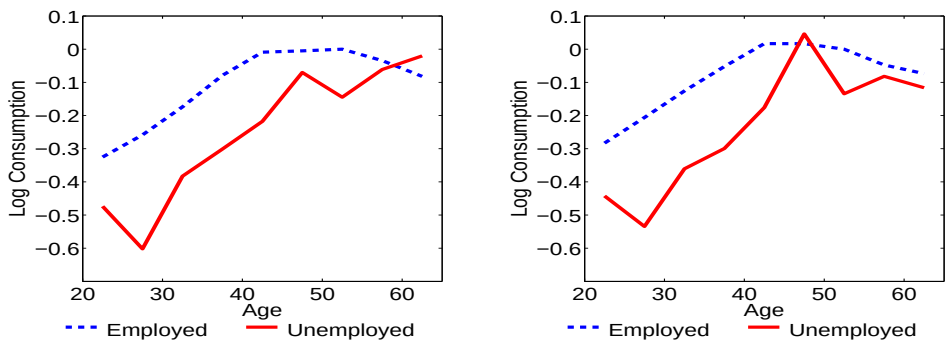
[8]The CPS results are robust to controlling for the maximum duration of benefits in the state and to instrumenting benefits using their own lagged value to deal with endogeneity problems—say because average benefits change over the business cycle due to changing composition in the pool of the unemployed (see Mueller, 2010). The IV estimates are larger and more in line with the estimates from the unemployment duration analysis, which might indicate that compositional changes raise income replacement rates in recessions.

3.3 Consumption while unemployed

To estimate how the consumption of unemployed workers varies with age, we run the following regression on PSID data:

$$\ln c_{it} = \sum_n \beta_n^e e_{it}^n + \sum_n \beta_n^u u_{it}^n + \theta X_{it} + err. \tag{16}$$

where i denotes the worker, t the year, c_{it} consumption per capita in the household, e_{it}^n and u_{it}^n are employment status dummies that are equal to one if, at the interview date, the household head of age n is employed or unemployed, respectively. Finally X_{it} are a set of controls, including dummies for the educational level and the race of the household head, time dummies and the number of household members. To account for serial correlation in the errors, a GLS random-effects estimator is used. Figure 2 shows the estimated age profile of consumption of employed



(a) Food consumption

(b) Non-durable consumption

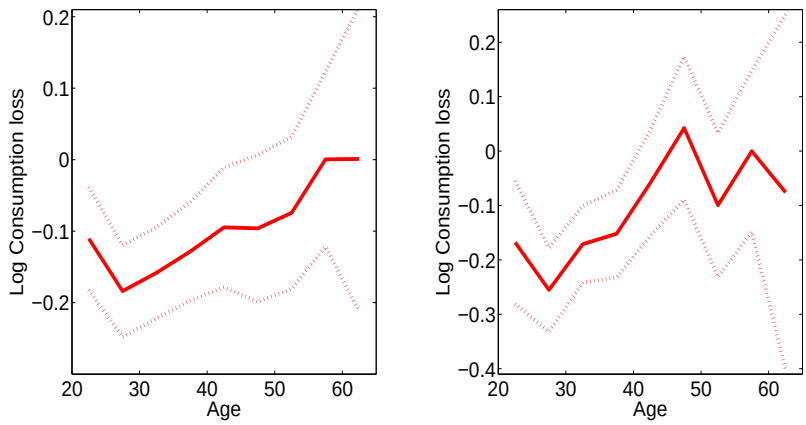
Notes: Life cycle profile of logged household per capita consumption. Equation (16) is estimated on PSID data. Left column is for food consumption, right column for total consumption expenditure on non-durables. The log consumption of employed workers 50-55 years of age is normalized to zero.

Figure 2: Food and total non-durable consumption by age, PSID

workers as a dashed line and of unemployed workers as a solid line. Panel (a) shows food consumption, panel (b) total non-durable consumption. The consumption of employed workers increases with age reaching a peak at around 50 years of age. That of unemployed workers also increases with age and is generally lower than that of the employed.[9]

[9]The results are robust to including temporarily laid-off workers among unemployed, to weighting observations, to using total food expenditures either at home or out of the home, and to dropping observations with consumption levels below the 1st or above the 99th percentile of the consumption distribution. We also find that consumption of unemployed workers increases with age not only on average but also in the first-order stochastic dominance sense.

We also estimate the age pattern of consumption losses upon unemployment. To do so, we follow Gruber (1997) and estimate equation (16) but now including individual fixed effects and dummy variables for changes in employment status. The resulting regression is estimated using a fixed-effects (within) regression estimator. The coefficient for the change in employment status from employed to unemployed characterizes the size of the average consumption loss. We allow this effect to vary by age. Figure 3 shows the age profile of consumption losses for food (left panel) and total non-durable consumption (right panel). Consumption losses are around 17% for workers in their twenties and thirties but less than 5% for those in their fifties and sixties.[10] Consumption losses are slightly greater for total non-durable consumption, but in both cases they fall significantly as age increases.



(a) Food consumption losses (b) Non-durable consumption losses

Notes: Consumption losses upon unemployment by age, PSID data. Dotted lines are 90 percent confidence intervals.

Figure 3: Consumption losses upon unemployment

3.4 Moral hazard and liquidity effects

These results indicate that unemployment insurance induces mild incentive costs and it is most valuable to young workers. We now provide more direct evidence that i) the moral hazard created by unemployment insurance is mild for young workers and ii) that they value unemployment insurance highly because they have limited other means to smooth consumption during unemployment.

[10] There is a substantial literature measuring consumption losses upon unemployment, see Gruber (1997), Browning and Crossley (2001), Bloemen and Stancanelli (2005) and Sullivan (2008). All studies note that average consumption losses result from aggregating vastly heterogenous individual responses. Our results indicate that part of this heterogeneity is life-cycle-related.

Moral hazard effects by age As is shown by Chetty (2008), UI benefits increase the duration of unemployment owing to a conventional moral hazard effect (benefits reduce the net income gains from finding a job) and a liquidity effect (benefits tend to equalize the marginal utility of consumption when employed and unemployed). So the evidence that the elasticity of unemployment to benefits increases with age does not necessarily indicate that the moral hazard problem is milder for younger than for older workers. Chetty (2008) argues that the severity of the moral hazard problem is measured by the job finding response to benefits of workers with high asset levels: wealthy workers have great ability to smooth consumption during unemployment, so liquidity effects are absent and benefits lengthen unemployment duration because of moral hazard alone. To pursue this logic, we use the SIPP data to estimate the following Cox regression for unemployment duration analogous to (14):

$$\ln h_{it} = \sum_n \beta_n q_{it}^n \ln b_{it} + \theta X_{itj} + err. \tag{17}$$

where q_{it}^n is an indicator variable equal to 1 if the worker's wealth is in quartile n (with higher n indicating greater wealth). Wealth quartiles are calculated for the entire sample. The results change little when wealth quartiles are age-specific. Controls are as in the estimation of equation (14) with the addition of wealth dummies and their interaction with unemployment duration. Table 2 reports the estimated β_n coefficients in the full sample and in the samples of 'young' and 'old' workers. There is evidence that benefits reduces the job finding rates of older workers with assets in the top two quartiles. The effects are somewhat stronger when measuring benefits with state averages. Standard significance tests also indicate that for older workers we cannot reject the null hypothesis that the effect of benefits is the same for the wealthiest as for the least wealthy. This is indirect evidence that benefits increase the unemployment duration of old workers mainly because of moral hazard, with liquidity effects being somewhat less important. For young wealthy workers UI benefits have no significant effect on unemployment. Overall the evidence is consistent with the thesis that the moral hazard inherent in unemployment insurance is more severe for older than for younger workers.

Liquidity effects by age Table 2 offers evidence that UI benefits increase the unemployment probability of young poor workers, especially when the measure used is individual benefits. This jibes with the idea that benefits provide valuable liquidity to young workers that enables them to better smooth consumption. The

Table 2: Elasticity of job finding to benefits by assets, SIPP

	(a) Individual UI benefits			(b) Age-specific average benefits		
	All	*20-40 yrs*	*41-60 yrs*	*All*	*20-40 yrs*	*41-60 yrs*
Q_1 x ln ben.	-.64***	-.55*	-1.32***	.12	-.49	-1.40*
	(.24)	(.30)	(.43)	(.20)	(.52)	(.74)
Q_2 x ln ben.	-.76***	-.93***	-.26	.02	-.49	-1.62*
	(.22)	(.24)	(.55)	(.20)	(.47)	(.96)
Q_3 x ln ben.	-.56***	-.31	-1.11***	.09	.39	-1.86***
	(.16)	(.25)	(.35)	(.20)	(.40)	(.49)
Q_4 x ln ben.	.02	.66	-.79*	.14	.95	-1.80***
	(.26)	(.35)	(.47)	(.21)	(.71)	(.50)
Q_1=Q_4 p-val	.09	.01	.34	.95	.03	.51
Q_1+Q_2=Q_3+Q_4 p-val	.06	.00	.67	.80	.00	.52
Q_1=Q_2=Q_3=Q_4 p-val	.18	.00	.25	.95	.00	.85
Number of spells	4054	2498	1420	4054	2498	1420

Notes: Estimates of β_n in the Cox regression (17) using SIPP data. Q_j, $j = 1, 2, 3, 4$ are the quartiles of the wealth distribution in the entire sample. Other details are as in Table 1.

age pattern of consumption losses upon unemployment in Figure 3 is also consistent with the view that young workers value unemployment insurance highly because they have little possibility of smoothing consumption during unemployment, as they have little precautionary savings and limited liquidity. We can now provide more direct evidence consistent with this view. We borrow from Chetty (2008) the idea that severance payments provide liquidity to unemployed workers with no moral hazard costs.[11] By comparing the search behavior of unemployed workers who have and who have not received severance payments, we can identify the importance of liquidity effects. As in Chetty (2008), we then exploit the fact that the Mathematica data contain information on whether displaced workers received severance payments at the time of the job loss, so we can estimate the following Cox proportional hazards regression analogous to (14):

$$\ln h_{it} \quad = \quad \beta Sev_i + \theta X_{it} + err. \tag{18}$$

where Sev_i is an indicator equal to 1 if the displaced worker has received a severance payment. The additional controls X_{it} include worker's age, four education dummies, splines in past tenure and past wages, the log of unemployment benefits, fixed effects for state, occupation and industry, unemployment duration dummies and the interaction of the severance payment dummy with unemployment du-

[11] Here we focus on the effects on search effort, but of course severance payments can affect workers' incentive to accumulate precautionary savings and in this sense they also induce a moral hazard problem.

ration. Again the model is estimated for the full sample and separately for the two age groups. The resulting estimate for β is reported in Table 3. The first column reproduces the full sample results in Chetty (2008), which indicate that unemployed workers with severance pay have job finding rates about a quarter lower. When we split the sample by age, the reduction in finding rates for younger workers is around a third, while for older workers it is close to zero and not statistically significant at conventional levels. This is again consistent with the idea that young workers have trouble smoothing consumption during unemployment, due to lack of liquidity.

Table 3: Elasticity of job finding to severance pay, Mathematica data

	All	*20-40 yrs*	*41-60 yrs*
Severance pay	-.23***	-.35***	-.08
	(.07)	(.09)	(.11)
Number of spells	2428	1514	790

Notes: Estimates of β in (18) using Mathematica data. Further details are as in Table 1.

4 The laboratory economy

We now consider a life cycle model with ongoing unemployment risk which we use as a laboratory economy to examine three questions: we study the magnitude of the welfare gains of age-dependent unemployment insurance, compare them with those under the unconstrained optimal scheme for unemployment insurance over the life cycle, and then analyze how accurately the simple formulas discussed in Section 2 identify welfare gains of age-dependent policies. We first characterize the economy. Then we turn to calibration and discuss key properties of the calibrated economy. The study of the first best policy is in Section 5, the analysis of age-dependent policies in Section 6.

4.1 Assumptions

There is a mass 1 of workers who live for $\bar{n}_w + \bar{n}_r$ periods. They are active in the labor market in the first $\bar{n}_w$ periods and retired in the last $\bar{n}_r$. Allowing for retirement is necessary in order to get an empirically plausible age profile of assets. Workers have discount factor β and receive utility from consumption $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, with $\sigma > 0$. They are born with no job, no human capital, $e = 0$, no assets, $a = 0$, and can save in a riskless bond that pays a constant interest rate r satisfying

$\beta = \frac{1}{1+r}$. Workers have limited ability to borrow, and their assets cannot be less than the borrowing limit l. In each period of employment, workers accumulate one unit of human capital and receive wages $w(e)$ that satisfy $w' \geq 0$ and $w'' \leq 0$. This formalizes the notion that there are positive but decreasing returns to labor market experience. Employed workers of age n lose their job with probability δ_n, and when unemployed they choose how intensively to look for a new job. We allow the separation rate to be age-dependent in order to match the age profile of unemployment in the data. Search intensity reduces the probability of unemployment and the amount of leisure.[12] We assume that a worker who receives job offers with probability $1 - \mu$ enjoys utility from leisure $\psi(\mu)$, with $\psi'(\mu) > 0$ and $\psi''(\mu) < 0$. Here μ denotes the within-period unemployment probability of a worker searching for a job. We adopt the same timing convention as Lentz and Tranaes (2005) and Chetty (2008), whereby successful search in a period leads to a job in the same period. If a worker of age n is jobless at the end of the period, he receives unemployment benefits which are a fraction ρ_n of his last wage in the job. At the end of each period of unemployment there is a probability γ of the worker's human capital being depreciated to an amount $\kappa(n, e) \leq e$, which is dependent on the worker's age n and human capital in his previous job e. If, at some point during the unemployment spell, worker's human capital has depreciated, the worker is re-employed with human capital $\kappa(n, e)$. This induces wage losses upon displacement, which increase substantially with age as is documented in Davis and von Wachter (2011) and Johnson and Mommaerts (2011). Unemployment and the associated human capital losses are the only source of risk. During the last $\bar{n}_r$ periods of their life, workers receive retirement pensions π which, as in Conesa, Kitao and Krueger (2009), are independent of earnings history. During employment, workers of age n pay income taxes that are a fraction τ_n of their labor income. Taxes finance the unemployment insurance program and retirement pensions. Like Hopenhayn and Nicolini (1997) and Shimer and Werning (2007, 2008), we assume that workers and government face the same interest rate and that government policies are actuarially fair. This implies that the expected present discounted value of all transfers received by the worker is equal to the present value of the tax revenue

[12] We model the moral hazard of UI by relying on search effort decisions. There is evidence from time use surveys that job search intensity is inversely related to the generosity of unemployment benefits (see Krueger and Mueller, 2010). But the moral hazard induced by UI generally leads both to a decrease in search effort and to an increase in reservation wages. Like Shimer and Werning (2007, 2008), we believe that the the main implications of the paper are little affected by whether the moral hazard is characterized in terms of search effort or of reservation wages.

he expects to pay over his working life.[13]

4.2 The worker's maximization problem

Let $c^e(n, e, a, a') = (1 - \tau_n)w(e) + (1 + r)a - a'$ denote the consumption of an employed worker of age $n \leq \bar{n}_w$ with human capital e and assets a, who chooses asset level a' for the next period. Since a' should be greater than the borrowing limit l, the value of being employed for this worker satisfies:

$$V(n, e, a) = \max_{a' \geq l} u\left(c^e(n, e, a, a')\right) + \beta\left[(1-\delta_n)V(n+1, e+1, a') + \delta_n J(n+1, e+1, a')\right] \tag{19}$$

where the last term incorporates the fact that with probability δ_n a worker of age n has to search for a new job, which has value

$$J(n, e, a) = \max_{\mu \in [0,1]} \psi(\mu) + \mu U(n, e, a) + (1 - \mu)V(n, e, a) \tag{20}$$

This uses the timing convention that search leads to a job in the period with probability $1 - \mu$; otherwise the worker remains unemployed, which has value

$$U(n, e, a) = \max_{a' \geq l} u(c^u(n, e, a, a')) + \beta\left(1 - \gamma\right) J(n+1, e, a') + \beta\gamma J^*(n+1, e, a') \tag{21}$$

where $c^u(n, e, a, a') = \rho_n w(e) + (1 + r)\, a - a'$ denotes current period consumption when unemployed at age n. With probability γ the worker undergoes a loss of human capital and the function J^* denotes the value of search after this loss. It satisfies the following Bellman equation

$$J^*(n, e, a) = \max_{\mu \in [0,1]} \psi(\mu) + \mu U^*(n, e, a) + (1 - \mu)V(n, \kappa(n, e), a), \tag{22}$$

which incorporates the assumption that after the loss in human capital the worker is reemployed with human capital $\kappa(n, e) \leq e$, where e is his human capital in the previous job.[14] In the expression above, U^* denotes the value of being unemployed after a loss in human capital, which satisfies

$$U^*(n, e, a) = \max_{a' \geq l} u(c^*(n, e, a, a')) + \beta J^*(n + 1, e, a') \tag{23}$$

[13] This government budget constraint can also be justified assuming that in every period new cohorts of workers enter the labor market, that the size of these cohorts increases at rate r over time and that the government budget is balanced, so that the total tax revenue net of transfers across cohorts is zero in each period.

[14] Notice that the human capital loss $e - \kappa(n, e)$ depends on age at reemployment and not at displacement. This is a simplifying assumption allowing to economize on the number of state variables.

where $c^*(n,e,a,a') = \rho_n w(e) + (1+r)\,a - a'$ denotes per period consumption and e refers to worker's human capital at the time of displacement. In writing (19), (21) and (23) we adopted the convention that $\mathrm{V}(\bar{n}_w+1,e,a) = U(\bar{n}_w+1,e,a) = U^*(\bar{n}_w+1,e,a) = \frac{1-\beta^{\bar{n}_r}}{1-\beta} u\left(c^r\left(a\right)\right)$where the last term is the value of retiring at $n = \bar{n}_w + 1$ with assets a, which is equal to the discounted value of consuming in every remaining period $c^r\left(a\right) = \pi + \frac{ra}{1-\beta^{\bar{n}_r}}$.

Government policies are actuarially fair in that the expected present value of the income taxes collected over the working life of a worker is equal to the present value of the UI benefits and retirement pensions the worker expects to obtain over his entire life. This implies the condition

$$\sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \rho_n w\left(e\right) \chi^u\left(n, de\right) + \sum_{n=\bar{n}_w+1}^{\bar{n}_r} \beta^n \pi \chi^r(n) = \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \tau_n w\left(e\right) \chi^e\left(n, de\right) \tag{24}$$

where the integrals are conventionally defined Lebesgue integrals (see Stokey, Lucas and Prescott, 1989). Here $\chi^e\left(n,e\right)$ denotes the measure of employed workers of age n and experience e, $\chi^u(n,e)$ denotes the mass of workers of age n who collect benefits and who were displaced with human capital e, and $\chi^r(n) = \int \chi^e\left(\bar{n}_w, de\right) + \int \chi^u\left(\bar{n}_w, de\right) = \chi^r$ denotes the measure of retired workers of age n, which is constant and independent of age.[15] Of course, since the mass of workers in the economy is 1, these three measures taken together form a probability measure: $\sum_{n=1}^{\bar{n}_w} \left[\int_{R^+} \chi^u\left(n, de\right) + \int_{R^+} \chi^e\left(n, de\right)\right] + \bar{n}_r \chi^r = 1$.

4.3 Calibration

The model is calibrated at quarterly frequency to data for male workers in the US. The parameters are determined jointly to match the calibration targets in Table 4. This process can be seen as estimation by indirect inference (see for example Gouriéroux, Monfort and Renault, 1993). The resulting parameter values are in Table 5. The Online Appendix contains details on the construction of the calibration targets in the data and in the model. We now discuss how the parameters are identified starting from moment conditions.

Technology We assume that workers are born at 20 years of age, are active for 45 years, $\bar{n}_w = 180$, and live 20 years after retirement, $\bar{n}_r = 80$. The wage function $w(e)$ is restricted to be non-decreasing and is characterized by a cubic spline at the ten skill knots reported in Table 5. The values at the knots are set to match

[15] For expositional simplicity we do not make these measures explicitly dependent on some policy-relevant state variables, such as assets or depreciation of human capital.

Table 4: Calibration targets and model fit

Moment condition	Data	Model	Source
Mean wages relative to 20 years old:			
21 - 24 years	1.12	1.14	CPS
25 - 29 years	1.37	1.39	CPS
30 - 34 years	1.60	1.62	CPS
35 - 39 years	1.76	1.76	CPS
40 - 44 years	1.85	1.84	CPS
45 - 49 years	1.93	1.89	CPS
50 - 54 years	1.93	1.92	CPS
55 - 59 years	1.90	1.93	CPS
Unemployment rate:			
21-24 years	.104	.104	CPS
25-34 years	.058	.058	CPS
35-44 years	.046	.046	CPS
45-54 years	.042	.042	CPS
55-64 years	.041	.041	CPS
Proportion of displaced workers with benefits who experience a wage loss	.57	.57	SIPP
Median wage loss upon re-employment:			
21-30 years	.00	.00	SIPP
31-50 years	-.07	-.07	SIPP
51-64 years	-.10	-.10	SIPP
Unemployment duration (in weeks):			
21-30 years	17.1	17.0	CPS
35-45 years	20.2	20.6	CPS
50-60 years	25.8	25.7	CPS
elasticity of unemployment to benefits:			
21-30 years	.24	.24	SIPP
35-45 years	.60	.60	SIPP
50-60 years	.80	.85	SIPP
UI benefit replacement rate	.50	.50	SIPP
Retir. pensions over mean wages	.39	.39	OECD
Minimum assets for workers of age ≤ 35 over mean quarterly total income:	-.61	-.60	SCF

Notes: Unless otherwise specified all statistics are averages for either the entire working-age population or the corresponding age group. The age profiles of wages, unemployment rates, and unemployment duration are from CPS data on a sample of working-age males for 1990-2010. The minimum asset level in the data comes from SCF in 2007 and it corresponds to the 5th percentile of the net worth of workers younger than 35 over the mean quarterly total income in the working age population. Wage loss statistics are from SIPP for 1996-2007, for working-age white males displaced from a full time payroll job and who have cashed UI benefits at some point during their unemployment spell. Displaced workers are identified as in Johnson and Mommaerts (2011). Retirement pensions statistic is from OECD (2007). UI benefits replacement rate is as in Chetty (2008). See the Online Appendix for further details on calibration targets in data and model.

the average wage levels for the eight age groups in Table 4, plus the normalization condition that $w(0) = 1$ and that wages are constant for workers in their sixties. The age profile of wages in the data is obtained from the CPS for 1990-2010, using a sample of working-age men: wages increase on average by around 90 per cent

over the life cycle.

The separation rate function δ_n is characterized by a five-value cubic Hermite spline with age knots at $n = 10, 40, 80, 120, 160$. To make sure that δ_n always lies in the interval $[0, 1]$ we impose the boundary constraints that for $n \leq 10$, $\delta_n = \delta_{10}$ while for $n \geq 160$, $\delta_n = \delta_{160}$. The five values of the spline are implicitly calibrated to match the average unemployment rate of the five age groups in Table 4. Henceforth in the construction of age groups, we drop workers aged 20 and 65 because in the model the former are mostly unemployed and the latter about to retire. The resulting δ_n function is plotted in the Online Appendix. The mean separation rate is 0.035 which is roughly consistent with the data on average job tenure and with the mean separation rate from JOLTS over the period 2005-2007.

To calibrate the borrowing limit l, we take the distribution of net worth of workers under 35, who are the most likely to be financially constrained in the model. In practice l is set to be equal to minus 61 percent of the mean quarterly total income (i.e. from both labor and capital) in the economy. In the 2007 Survey of Consumer Finances (SCF) this corresponds to the 5th percentile of the distribution of the net worth of these workers over average quarterly income (from labor and other sources) in the Survey.

Table 5: Parameter values

Parameter	Definition	Value
$\bar{n}_w$	Working periods	180
$\bar{n}_r$	Periods in retirement	80
β	Discount factor	.99
ρ	UI benefit replacement rate	.50
π	Retirement pension level	.66
l	Borrowing constraint	-1.12
σ	Risk aversion	2.0
τ	Tax rate	.0707
$w(e)$	Wages at $e = 20j$, $j = 0, 1, ..., 9$	$\{1.0, 1.29, 1.56, 1.73, 1.84, 1.92, 1.95, 1.96, 1.97, 1.97\}$
δ_n	Separation rate (in percentage) at $n = \{10, 40, 80, 120, 160\}$	$\{8.5, 3.49, 3.07, 2.44, 2.13\}$
γ	Wage loss probability parameter	.41
$\overline{\kappa}_n$	Wage losses at $n = \{1, 40, 80, 160, 180\}$	$\{1, 1, .93, .90, .899\}$
$\psi(\mu)$	Search effort function at $\mu = \{0, .25, .47, .75, 1.0\}$	$-\{7.25, 1.78, .49, .021, -.203\}$

Notes: The functions $w(e)$, δ_n, $\overline{\kappa}_n$, and $\psi(\mu)$ are cubic splines through values in table.

Wage losses upon re-employment To calibrate the human capital loss function $\kappa(n, e)$ and the wage loss probability parameter γ, we use information on wage losses upon re-employment from SIPP over the period 1996-2007. We take a sample of working-age white males displaced from full-time payroll jobs and who

have received UI benefits at least at some point during their unemployment spell.[16] Wage losses are measured as the log difference between the wage in the last job in the month before displacement and the wage in the new job in the first month after reemployment. The median wage loss in our data is zero for workers under 30 and increases to around 10 percent for workers above 50.

To characterize the human capital loss function $\kappa(n, e)$, we assume that if the worker's human capital has depreciated during unemployment, the worker is re-employed with a wage that is a fraction $\overline{\kappa}_n$ of his previous wage $w(e)$. This implies that $\kappa(n, e) = w^{-1}(\overline{\kappa}_n w(e))$, where w^{-1} is the inverse function of $w(e)$, which is well defined since $w(e)$ is non-decreasing in e.[17] The wage loss function $\overline{\kappa}_n$ is characterized by a five-value cubic Hermite spline with knots at the age levels $n = 1, 40, 80, 160, 180$. The five values at the age knots are chosen to match the median wage losses for the three age groups in Table 4 plus the boundary constraints that for $n \leq 40$, $\overline{\kappa}_n = \overline{\kappa}_{40}$ while for $n \geq 160$, $\overline{\kappa}_n = \overline{\kappa}_{160}$ which guarantees that $\overline{\kappa}_n$ always lie in the $[0, 1]$ interval. The resulting $\overline{\kappa}_n$ function is plotted as a dotted line in panel (a) of Figure 14. The parameter γ, the probability of a wage loss, is chosen so that a worker who collects UI benefits at some point during his job search spell has a 57 percent probability of experiencing a wage loss upon re-employment, which is in line with evidence from our SIPP sample.[18]

Search effort To characterize the within-period unemployment probability function $\psi(\mu)$ we start by observing that the second derivative of the function ψ is crucial in determining the value of the elasticity of unemployment to benefits. Accordingly we model its profile explicitly and constrain it to always be non-positive, $\psi'' \leq 0$ (see the Online Appendix for further details). In practice the ψ function is approximated by a cubic spline evaluated at the five age knots reported in Table 5, with the middle knot corresponding to the endogenously determined value of μ at which the second derivative of ψ peaks (i.e. reaches its minimum absolute value). The six moment conditions needed to pin the function down are the aver-

[16] We do not use earlier panels in SIPP because they lack detailed information on why respondents leave their jobs, which we use to separately identify quits from dismissals. To focus on displacement for exogenous reasons, we classify unemployed workers as displaced if they report separating from their employer because of layoff, slack work, employer bankruptcy, or because the employer sold the business, which follows Johnson and Mommaerts (2011).

[17] For the range of values of e for which the $w(e)$ function is constant, the inverse function w^{-1} is defined as selecting the minimum value of e over the corresponding range.

[18] The values of $\overline{\kappa}_n$ at the age knots are similar to the median wage losses of the corresponding age groups in Table 4. This is because the wage loss of a re-employed worker of a given age n is a binary random variable, with a mass probability at zero which is less than half. So the median wage loss coincides with the positive wage loss, $1 - \overline{\kappa}_n$, experienced by workers whose human capital has depreciated during unemployment.

age unemployment duration and the elasticity of unemployment to benefits for the three age groups reported in Table 4. In the model, the elasticity for workers of age n, η_n, is calculated considering changes in replacement rates at p consecutive quarters starting from age n. To be sure, let $\rho = \{\rho_1, ..., \rho_{\overline{n}_w}\}$ denote the vector containing the age profile of UI replacement rates in the baseline economy. For every n, the unemployment elasticity, η_n, is calculated considering two economies, one with lower and one with higher replacement rates at age n than in the baseline economy.[19] The resulting $\psi(\mu)$ function is depicted in panel (a) of Figure 4.

Remaining preferences We set β to .99, to match an annual interest rate of approximately 4%. The CRRA parameter σ is chosen to be equal to 2, as in Conesa, Kitao and Krueger (2009) when using a specification with separable utility between consumption and leisure.

Policy parameters The income replacement rates of benefits ρ_n are assumed to be equal to a constant value ρ, which following Chetty (2008) is calibrated to .5.[20] The retirement pensions π are set equal to 0.662, which yields a ratio of retirement pensions over mean quarterly labor income of 0.39 in line with aggregate statistics from OECD (2007). The tax rate $\tau = 7.07\%$ keeps the government budget constraint in (24) satisfied.

4.4 Further properties of the calibrated economy

Panels (b)-(h) of Figure 4 characterize the age profile of key variables in the model economy and in the data. In all panels, the solid blue line corresponds to the model, the dashed and dotted red lines to the data. To facilitate comparison, we form the age groups 21-25, 26-35, 36-45, 46-55, and 56-64. As before we ex-

[19]The lower and the higher replacement rates at age n are characterized by the vector $\rho_n^i = \{\rho_1, ..., \rho_{n-1}, \vartheta_n^i, \vartheta_{n+1}^i, ..., \vartheta_{n+p-1}^i, \rho_{n+p}, .., \rho_{\overline{n}_w}\}$, $i = l, h$ where $\vartheta_{n+j}^l = \rho_{n+j} - \frac{\epsilon}{2}$ and $\vartheta_{n+j}^h = \rho_{n+j} + \frac{\epsilon}{2}, \forall j = 0, 1, ...p-1$. In the paper we work with $\epsilon = 0.02$ and $p = 4$, which corresponds to a change in benefits for an age group of one year. We checked that results are not greatly affected by reducing ϵ or p. We consider changes in benefits for p consecutive quarters both to increase sample size and to reduce the likelihood that the policy change affects workers' search effort decisions through effects on unemployment duration dependence in benefits, which is an issue somewhat unrelated to age-dependent policies. To avoid this problem we could have indexed the level of replacement rates not to current age but to the age at which the worker is displaced. But this alternative specification would require an additional state variable, which would involve additional computational costs.

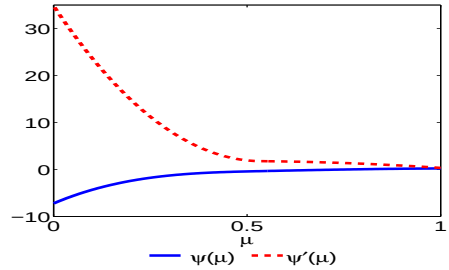
[20]In practice, replacement rates in the US are not completely independent of age since wages are typically replaced by a constant percent but with a cap. This implies that effective replacement rates are lower for groups with higher wages (such as older workers). Matching this feature of the US system would require making UI replacement rates a function of both n and e. In any case age differences in actual replacement rates are small (about 10 percent) compared with those that arise under the optimal age-dependent policies studied in Section 6.

clude workers aged 20 and 65 because in the model they are mostly unemployed or on the verge of retirement. We then calculate averages for wages (panel b), unemployment rates (panel c), unemployment duration (panel e) and net assets over average quarterly total income in the economy (panel h). Data averages for the elasticity of unemployment to benefits (panel e), consumption when unemployed (panel f), and consumption differences between employed and unemployed (panel g) correspond to the analogous profiles in Figures 1 and 2. The model matches well the profile of wages, unemployment rates and unemployment duration, panels (b)-(d). All these were explicitly used as calibration targets. The model just tends to over-predict the unemployment duration of workers in their early sixties. This is because the ψ function in panel (a) is strictly positive at a within-period unemployment probability equal to 1, so unemployed workers close to retirement always tend to shirk. The unemployment risk faced by workers over their working life is sizeable: around 24 per cent of workers have to search for a new job in at least one out of ten periods of their working life. The model also matches the age profile of the elasticity of unemployment to benefits in the data reasonably well: the model counterpart tends to lie between the estimated value based on the unemployment duration analysis in SIPP and the value obtained using aggregate state level data from CPS.

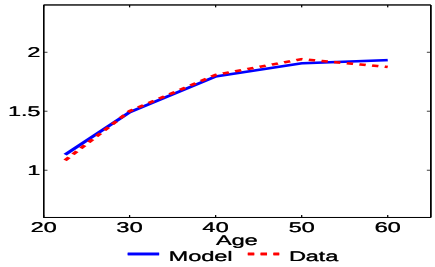
As regards consumption, the model approximates moderately well the age profile of consumption when unemployed in the data (panel f), although the model tends to reach a plateau a couple of years earlier. Also the model's profile of consumption losses upon unemployment—as measured by the log difference between the average consumption of the employed and the unemployed—is reasonably in line with the data. Finally panel (h) shows the age profile of net assets. Asset levels are higher in the data, but overall the model reproduces the average increase of assets over the life cycle quite well. This is remarkable, considering that the calibration used no information on consumption and only limited information on assets.

4.5 Elasticities and redistribution formulas

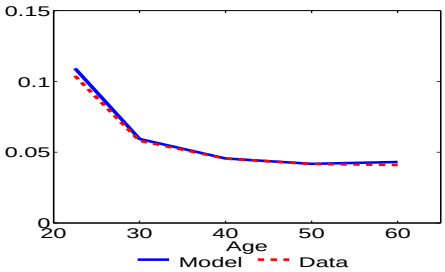
Panel (a) of Figure 5 plots the age profile of the simple redistribution formula ϱ_n in (8) as a solid blue line and that of the extended redistribution formula $\widetilde{\varrho}_n$ in (11) as a dashed red line. The simple redistribution formula is calculated as $\varrho_n = \frac{u'(c_{un})}{1+\eta_n}$ where c_{un} denotes the expected consumption of unemployed workers



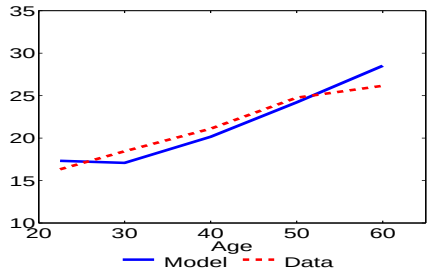
(a) Search effort function, $\psi(\mu)$



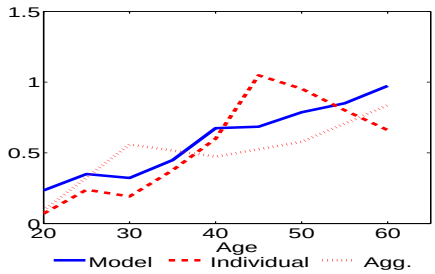
(b) Wages



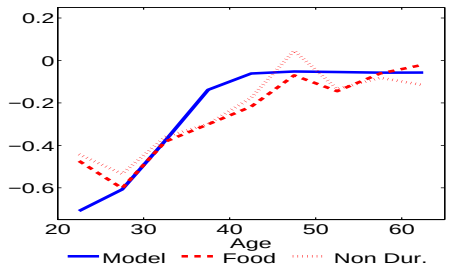
(c) Unemployment rates, u_n



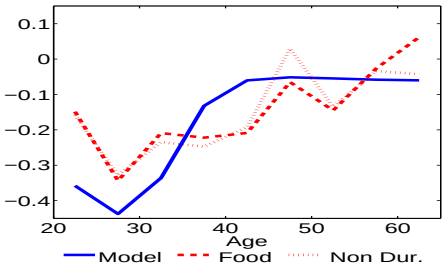
(d) Unemployment duration



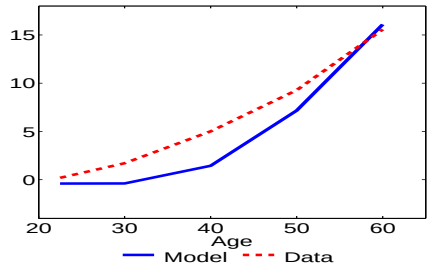
(e) Unemp. elasticity to benefits, η_n



(f) Consumption of unemployed, $\ln c_{un}$



(g) Unemp. consumption loss, $\ln(c_{un}/c_{en})$



(h) Assets over aggregate income

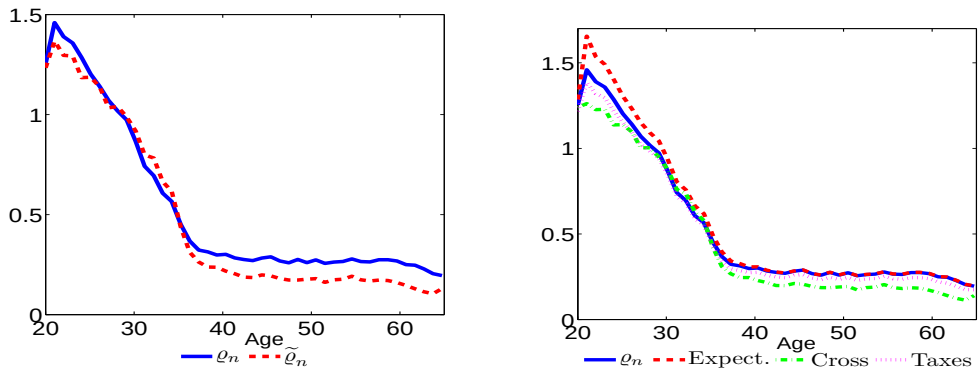
Notes: With the exception of panel (a), solid blue lines correspond to model, dashed and dotted red lines to data. The dashed red lines in panel (b), (c), and (d) are from CPS. Dashed and dotted red lines correspond: in panel (c) to panel (a) and (b) of Figure 1, respectively; in panel (d) to the solid red lines in panel (a) and (b) of Figure 2, respectively; in panel (e) to differences between solid red line and dashed blue line in panel (a) and (b) of Figure 2, respectively. Dashed red line in panel (e) is the ratio between households' net worth in the age group and households' average quarterly total income in SCF. In panel (f) the log consumption of employed workers aged 50-55 is normalized to zero, which is as in Figure 2.

Figure 4: Properties of laboratory economy

of age n. To calculate $\widetilde{\varrho}_n$ at each n we again exploit changes in income replacement rates at p consecutive quarters starting from age n. We use these policy changes to calculate the cross elasticity of unemployment

$$\widetilde{\eta}_n = \sum_{i=1}^{\bar{n}_w} \frac{\partial \mu_i}{\partial \rho_n} \cdot \frac{\beta^i \rho_i}{\beta^n \mu_n}, \tag{25}$$

which is analogous to (12). Here $\mu_n \equiv \int_{R^+} \chi^u(n, de)$ denotes the mass of workers of age n who collect benefits. We also define the present value of total tax revenue as equal to $\mathrm{T}(\rho) = \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \tau_n w(e) \chi^e(n, de)$ and calculate the derivative of T with respect to the age-dependent change in benefits. We then use (11) to calculate $\widetilde{\varrho}_n$ (see the Online Appendix for further details).



(a) Redistribution formula: ϱ_n and $\widetilde{\varrho}_n$

(b) Decomposition of ϱ_n

Figure 5: Comparison between simple, ϱ_n, and extended, $\widetilde{\varrho}_n$, redistribution formula

The age profiles of ϱ_n and $\widetilde{\varrho}_n$ in Figure 5 are remarkably similar, which indicates similar welfare gains from redistributing unemployment insurance over the life cycle. Both ratios are generally decreasing with age and have values close to 1.5 for workers in their twenties and close to 0.25 for those in their forties and early fifties. On the whole, this suggests that one unit of government money would yield six times more welfare gains when assigned to young unemployed workers than to middle-aged unemployed workers. As is implied by the discussion in Section 2.3, there are three reasons why in the baseline calibration ϱ_n differs from $\widetilde{\varrho}_n$: (i) ϱ_n focuses on the marginal utility of expected consumption, not the expected marginal utility of consumption; (ii) ϱ_n misses the effects of age-specific changes in benefits on the unemployment level of age groups other than those directly targeted by the change in benefits; and (iii) ϱ_n neglects the effects of UI on tax

revenue.[21] Since the marginal utility of consumption is convex, effect (i) tends to make ϱ_n less than $\widetilde{\varrho}_n$ while effects (ii)-(iii) tend to make it greater. To analyze the contribution of each factor separately, in panel (b) of Figure 5 we compute ϱ_n adding one source of difference at a time: the solid blue line corresponds to the profile of ϱ_n in panel (a); the dashed red line is analogous, but with ϱ_n calculated using the expected marginal utility of consumption rather than the marginal utility of expected consumption; the dash-dotted green line corresponds to calculating ϱ_n using the extended elasticity of unemployment $\widetilde{\eta}_n$ in (25) rather than the simple elasticity η_n; and finally the dotted purple line is obtained by calculating ϱ_n after adding to the denominator the effect of taxes, as measured by $\frac{\partial T}{\partial b_n} \cdot \frac{1}{\mu_n}$. For workers under 40, consumption is low, which makes the marginal utility of consumption highly convex. For these workers the positive effect on $\widetilde{\varrho}_n$ of taking expectations almost exactly cancels out the negative effects on $\widetilde{\varrho}_n$ due to unemployment cross-derivatives and taxes. So the simple and extended formulas, $\widetilde{\varrho}_n$ and ϱ_n, almost overlap in panel (a). But for workers above 40, consumption is high enough to make the marginal utility of consumption almost linear. For these workers, the effects of cross-derivatives and taxes necessarily dominate, so $\widetilde{\varrho}_n$ falls below ϱ_n.

5 Optimal life cycle unemployment insurance

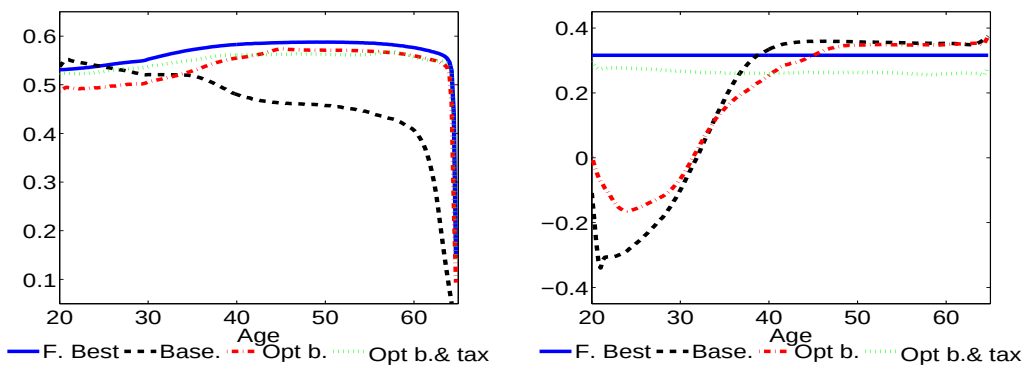
At birth, workers have to look for a job, they have no experience and no assets so their welfare is given by $W_s \equiv J(1,0,0)$. Before analyzing age-dependent policies, let us study the first best problem faced by an agency that observes workers' assets and search effort and maximizes initial worker's utility W_s by choosing benefits ρ, taxes τ, and pensions π as a function of the worker's entire history. The government budget is balanced, so an expression analogous to (24) holds. Since assets are observable, we can posit that the agency directly controls workers' consumption. Search effort too is observable, so there is no moral hazard problem and the agency can achieve perfect consumption smoothing by guaranteeing the worker a constant consumption level c through his entire life. As a result consumption losses upon unemployment are zero. Let $\Upsilon(n,e,c)$ denote the total net cost of providing a constant consumption flow c to a worker of age $n \leq \bar{n}_w$ with human capital e who has just started looking for a job. This cost is equal to the difference

[21] In the baseline calibration $\rho_n > 0$, $\forall n$, so the feasibility constraint is never binding and ω_n in (11) is always equal to zero.

between the present value of consumption expenditure and the expected present value of the income $Y(n,e,c)$ generated by the worker:

$$\Upsilon(n,e,c) = \frac{1-\beta^{\bar{n}_w+\bar{n}_r+1-n}}{1-\beta}c - Y(n,e,c) \tag{26}$$

In each period the within-period unemployment probabilities are set to maximize the utility value of Y net of the disutility cost of job search (see the Online Appendix for details). The function $\Upsilon(n,e,c)$ in (26) is decreasing in c, because higher consumption implies greater expenditure and lower future income Y, as higher c reduces search effort due to a conventional income effect. The optimal value of c, denoted by c^*, is set to make $\Upsilon(n,e,c)$ at worker's birth equal to zero $\Upsilon(1,0,c^*) = 0$.The solid line in panel (a) of Figure 6 characterizes the age profile of job finding rates under the optimal policy. The finding rate for workers



(a) Finding rate, f_n

(b) Consumption of unemployed, $\ln c_{un}$

Notes: Solid lines correspond to the first best economy; dotted lines to the baseline economy; dashed lines to the economy with age-dependent replacement rates; dash dotted lines to the economy with age-dependent replacement rates and tax rates.

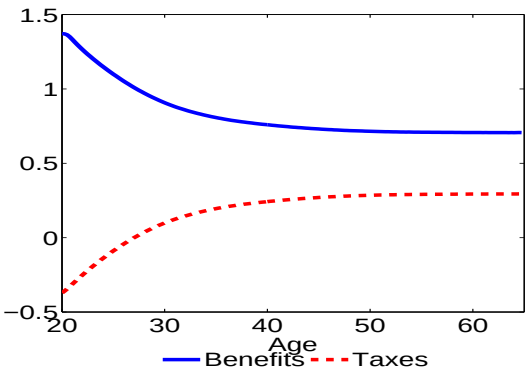
Figure 6: First best policy and optimal age-dependent policies

of age n, f_n, is simply the ratio between the number of workers of age n who find a job in a period and the number of workers of the same age searching for a job.[22] Finding rates are slightly increasing with age until two years before retirement, when they fall rapidly to zero. Since the ψ-function is concave, the

[22]Let $\chi^s(n,e) = \chi^u(n-1,e) + \delta_{n-1}\chi^e(n-1,e-1)$ denote the measure of workers of age n searching for a job who had human capital e at the time of displacement. Notice that $\chi^s(n,e)$ is the sum of two terms: the first is the mass of workers of age $n-1$ who collect benefits in a period and who will search for a job in the next period when they are one period older; the second is the fraction δ_{n-1} of employed workers of age $n-1$ and human capital $e-1$ losing their job. With this notation we have that the number of workers of age n searching for a job is $\sigma_n = \int_{R^+}\chi^s(n,de)$, which allows us to express the job finding rate as equal to $f_n = \frac{\sigma_n-\mu_n}{\sigma_n}$.

agency would like to smooth search effort over time, but the opportunity cost of having an old, typically high-skilled worker unemployed is high in view of his high productivity. So finding rates slightly increase with age. Just before retirement, search is unprofitable since little time is left to capitalize on the investment, so finding rates drop to zero.

To analyze the profile of income replacement rates under the optimal policy, we follow the optimal unemployment insurance literature (Hopenhayn and Nicolini, 1997) and define $\frac{c^*}{w(e)}$ as the optimal replacement rate of a worker whose human capital at the time of displacement was equal to e. Similarly we can consider an employed worker with human capital e and define the tax rate implied by the optimal policy as equal to $1 - \frac{c^*}{w(e)}$: Figure 7 characterizes the age profile of the average replacement rate (solid line) and average tax rates (dashed line). Since wages $w(e)$ tend to increase with age and the agency guarantees perfect consumption insurance to workers, we have that replacement rates are on average decreasing with age while tax rates are increasing. Table 6 compares welfare under the optimal policy and in the baseline economy.[23] Gains relative to the status quo are sizable, roughly equivalent to a 3.4 per cent increase in per period consumption.



Notes: Age profiles of UI income replacement rate, $\frac{c^*}{w(e)}$, (solid blue line) and income tax rate, $1 - \frac{c^*}{w(e)}$, (dashed red line) as implied by the first best policy.

Figure 7: Income replacement rates and tax rates in first best policy

[23]In the baseline economy the average income replacement rate of UI benefits might not be optimal. To better isolate the effects of age-dependent policies, welfare gains are always measured relative to the economy with an optimal replacement rate. In practice, like many others (see Davidson and Woodbury 1997, Shimer and Werning 2007, Pavoni 2007, and Chetty 2008), we find that the optimal replacement rate—0.51—is close to the actual US level. Differences with the baseline economy of Section 4 are therefore minimal.

6 Age-dependent policies

In the previous section transfers could be conditional on workers' entire labor market history as well as on their assets, age, experience, and employment status, thus guaranteeing perfect consumption insurance. We now study age-dependent policies, where the government can make income replacement rates, ρ_n, and labor income tax rates, τ_n, conditional on age n alone. Pension levels are left unchanged, while tax levels are always adjusted to satisfy the government budget constraint (24).

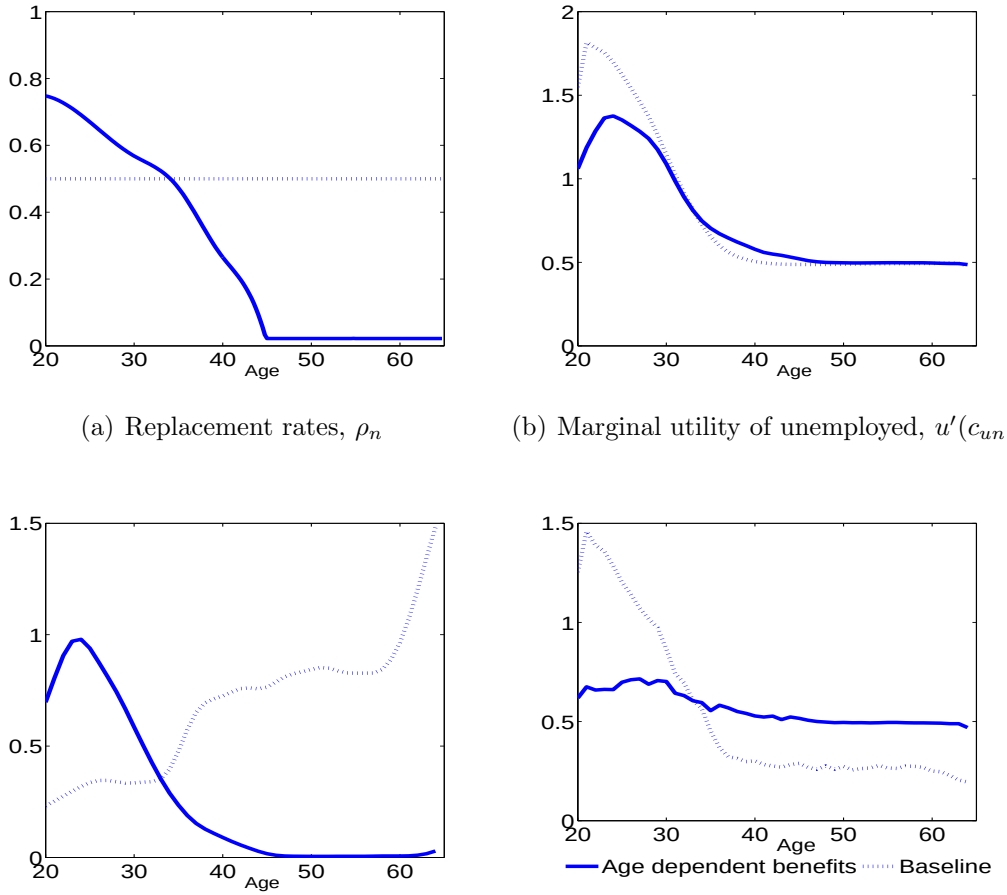
6.1 The problem

An optimal age-dependent income replacement rate policy is a choice for the vector of replacement rates ρ that maximizes $W_s \equiv J(1,0,0)$ subject to the budget constraint in (24), workers' optimal choices as implied by (19)-(22), and a feasibility constraint that requires replacement rates to be non-negative $\rho \geq 0$.[24] We model ρ_n as the maximum between zero and a cubic spline at the ten age knots corresponding to $n = 1, 20, 40, 60, 80, 100, 120, 140, 160, 180$. We search for the value at the knots that maximize workers utility at birth W_s and check that the results are not altered greatly by increasing the number of knots. We then allow income tax rates also to vary with age. This problem is analogous to the foregoing: the government chooses $\rho \geq 0$ and the vector of tax rates τ to maximize W_s subject to exactly the same constraints. To solve this problem, we again assume that ρ_n and τ_n are a cubic spline at the previously defined age knots where the former function is restricted to be non-negative. For each policy, we study how replacement rate and tax rates vary by age and analyze the properties of the ϱ_n ratio in (1) as well of the modified redistribution formula $\widetilde{\varrho}_n$ in (11). We then quantify the gains from age-dependent policies and compare them with those attained under the optimal life cycle unemployment insurance problem of Section 5. In comparing welfare gains we also consider an economy in which the income replacement rates of unemployment insurance are maintained at the current US level, while the age profile of labor income tax rates τ is chosen to maximize W_s subject to exactly the same constraints as before.

[24] We impose this constraint because the worker could always opt to drop out of the labor market and so receive zero benefits.

6.2 Optimal policies

The solid lines in the four panels of Figure 8 characterize the economy with optimal age-dependent replacement rates and constant income tax rates. Dotted lines



(a) Replacement rates, ρ_n

(b) Marginal utility of unemployed, $u'(c_{un})$

(c) Elasticity of unemployment, η_n

(d) Redistribution formula, ϱ_n

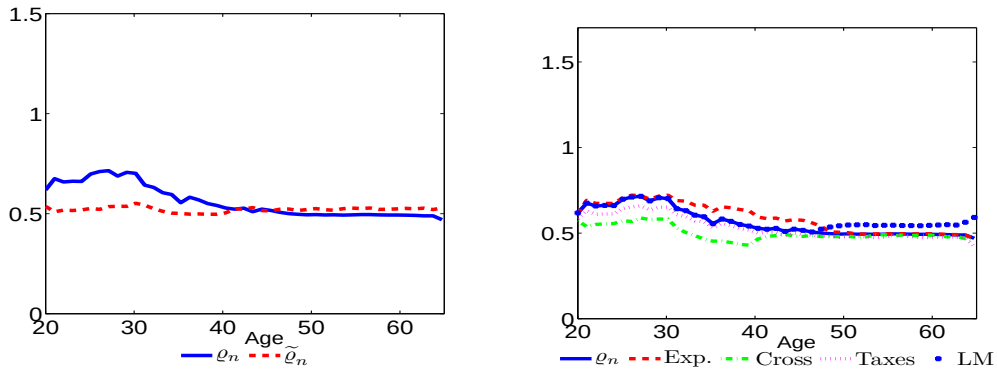
Notes: Dotted lines correspond to the baseline economy, solid lines to the economy with optimal age-dependent income replacement rates from UI and constant income tax rates.

Figure 8: Age-dependent replacement rates only

correspond to the baseline economy of Section 4. Panel (a) shows the optimal age profile of replacement rates, panel (b) the profile of the marginal utility of average consumption when unemployed, panel (c) the elasticity of unemployment to benefits, and panel (d) the profile of ϱ_n as previously defined. Under the optimal age-dependent policy, replacement rates are raised from the current value of 50 per cent to around 80 percent for workers in their mid-twenties and to 60 per cent for those in their thirties. Workers in their forties and fifties, by contrast, get almost no benefits. The age profile of the average marginal utility of consumption when

unemployed is substantially flatter than in the baseline economy. The elasticity of unemployment to benefits, η_n, is generally smaller than in the baseline economy and tends to decrease with age. Because of this, the age profile of the ϱ_n ratio is now substantially flatter than in the baseline economy.

Let us consider why ϱ_n does not become completely independent of age under the optimal age-dependent UI benefits policy. In panel (a) of Figure 9 we plot the age profiles of ϱ_n and $\widetilde{\varrho}_n$ in the economy with optimal age-dependent income replacement rates. As expected, $\widetilde{\varrho}_n$ is approximately flat while ϱ_n is greater than $\widetilde{\varrho}_n$ for workers under 40 and lower for those over 40. To see why the two profiles



(a) Redistribution formula: ϱ_n and $\widetilde{\varrho}_n$

(b) Decomposition of ϱ_n

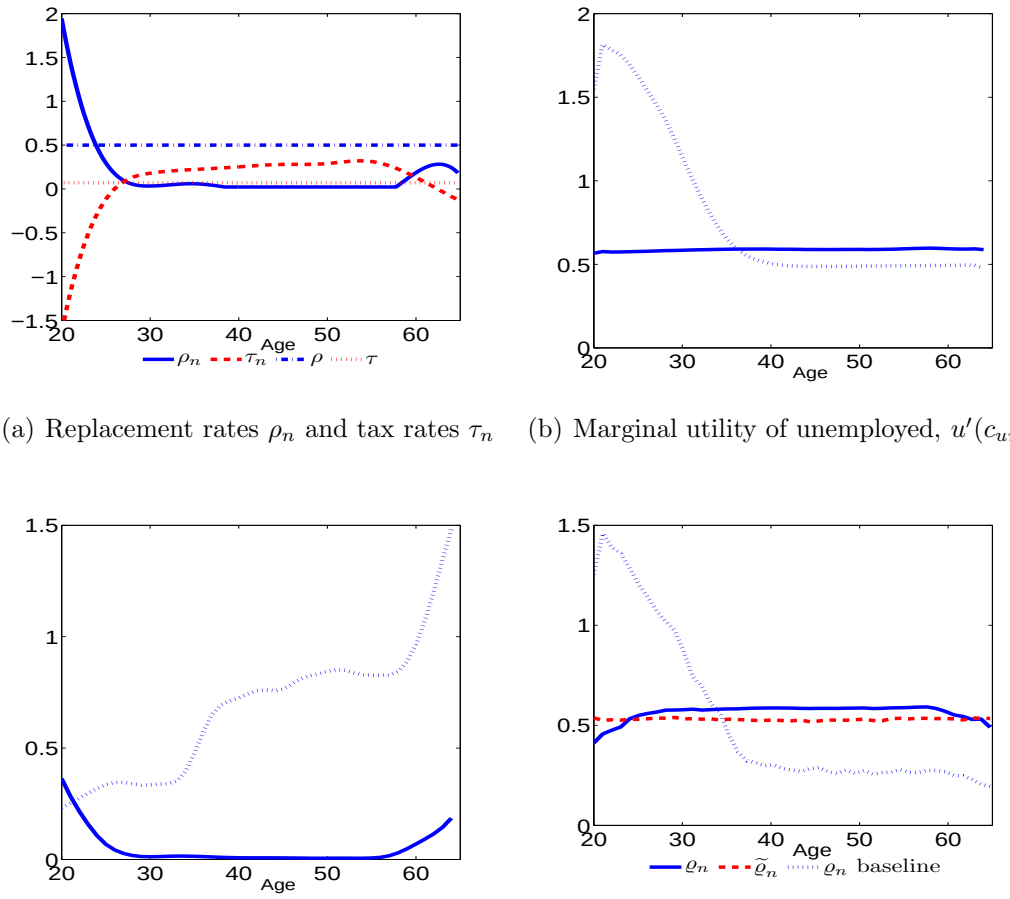
Notes: Lines are as in Figure 5 except for the bold blue dotted line in panel (b), which corresponds to the effects of the Lagrange multiplier on the feasibility constraint $\rho_n \geq 0$.

Figure 9: ϱ_n and $\widetilde{\varrho}_n$ in the economy with optimal age-dependent UI benefits

differ, we perform a decomposition exercise identical to that in panel (b) of Figure 5 but now also taking into account that for workers older than 40 the feasibility constraint $\rho_n \geq 0$ is binding, so that the Lagrange multiplier ω_n in (11) is strictly positive. The contribution of the Lagrange multiplier corresponds to the bold blue dotted line in panel (b), which is obtained by calculating ϱ_n after adding to the numerator in (1) the Lagrange multiplier $\frac{\omega_n}{\mu_n}$, which is positive when the feasibility constraint $\rho_n \geq 0$ is binding. All the other lines are as in panel (b) of Figure 5: the solid blue line corresponds to the profile of ϱ_n in panel (a); the dashed red line is analogous, but with ϱ_n calculated using the expected marginal utility of consumption rather than the marginal utility of expected consumption; the dash-dotted green line corresponds to calculating ϱ_n using the elasticity of unemployment extended to include cross-derivatives $\widetilde{\eta}_n$, not the simple elasticity η_n; finally the dotted purple line is obtained by calculating ϱ_n after adding to the

denominator the effect of taxes, as measured by $\frac{\partial T}{\partial b_n} \cdot \frac{1}{\mu_n}$. For workers under 40, ϱ_n is greater than $\widetilde{\varrho}_n$ mainly because $\widetilde{\eta}_n$ is greater than η_n—that is, because changes in benefits for one age group increase unemployment for other age groups as well. For workers above 40, ϱ_n falls below $\widetilde{\varrho}_n$ just because the feasibility constraint $\rho_n \geq 0$ is binding, which makes the Lagrange multiplier $\frac{\omega_n}{\mu_n}$ strictly positive.

Figure 10 is analogous to Figure 8, but now we also optimally choose the age profile of labor income tax rates. Taxes are generally set to achieve a smooth age profile of consumption. Tax rates increase with age until the very late fifties when they start to fall steeply until retirement. Taxes before retirement are low



(a) Replacement rates ρ_n and tax rates τ_n

(b) Marginal utility of unemployed, $u'(c_{un})$

(c) Elasticity of unemployment, η_n

(d) Redistribution formula, ϱ_n and $\widetilde{\varrho}_n$

Notes: In all panels dotted lines correspond to the baseline economy, solid lines to the economy with optimal age-dependent income replacement rates from UI and labor income tax rates. In panel (d) the dashed red line corresponds to the profile of $\widetilde{\varrho}_n$ in the economy with optimal age-dependent policies.

Figure 10: Age-dependent replacement rates and tax rates

in order to provide strong incentives to highly productive older workers, as well as

to finance high consumption during retirement.[25] The age profile of replacement rates is decreasing in age as in Figure 8, but now the rates are significantly lower for workers in their thirties. Just before retirement, benefits increase slightly, which follows from the analysis of $\widetilde{\varrho}_n$ in (11): for this age group tax rates are negative, so $\frac{\partial T}{\partial b_n}$ is positive, which pushes up the value of $\widetilde{\varrho}_n$ and thereby justifies increasing ρ_n. The age profiles of the marginal utility of consumption when unemployed and of the elasticity of unemployment to benefits become substantially flatter than in the baseline economy. As a result the profile of ϱ_n becomes almost invariant to age except for very young and very old workers, for whom ϱ_n falls to around ten percentage points below its average. As expected, the age profile of $\widetilde{\varrho}_n$ is completely flat (dashed line in panel (d)). A decomposition exercise analogous to the one performed in panel (b) of Figure 9 shows that almost all the differences between ϱ_n and $\widetilde{\varrho}_n$ are due to the age profile of taxes: when taxes are negative, $\frac{\partial T}{\partial b_n}$ in (11) is positive, which makes $\widetilde{\varrho}_n$ greater than ϱ_n; when taxes are positive, $\frac{\partial T}{\partial b_n}$ is negative and $\widetilde{\varrho}_n$ falls below ϱ_n.

6.3 Welfare comparisons

Figure 6 characterizes the age profile of job finding rates (panel a) and consumption when unemployed (panel b) in the baseline economy (dotted line), in the economy with optimal age-dependent benefits (dashed line), in the economy with the combined age-dependent policy for benefits and taxes (dash dotted line) and in the optimal problem studied in Section 5 (solid line). Age profiles in the four economies do differ. In the first-best economy and under age-dependent policy, job finding rates are mildly increasing with age. Both in the first best economy and in that with combined age-dependent benefits and taxes, consumption is flat and consumption losses are small and relatively independent of age. In the baseline economy, finding rates are strongly decreasing in age, consumption is increasing and consumption losses are large for workers in their twenties and thirties.

Table 6 quantifies the welfare gains under the different allocations. The first best policy with observable search effort yields welfare gains equivalent to a 3.4% increase in consumption. The table normalizes these gains to 100% and compares them with those attained under alternative age-dependent policies. With age-

[25] Since the retirement age is exogenous, workers in their sixties have little incentive to search for a job. Moreover we are not maximizing with respect to the level of retirement pensions π, which affects the choice for the age profile of taxes before retirement: when we double the value of π, taxes fall significantly less in the five years before retirement.

dependent income replacement rates, welfare gains are equivalent to just under a 1% increase in lifetime consumption. Combining age-dependent unemployment insurance with age-dependent taxes, the gain rises to 3.2%. That is, simple age-dependent policies yield more than 90% of the welfare gains of the optimal unemployment insurance program.[26] It is also useful to study the economy where the

Table 6: Welfare comparisons

Economy	Welfare gains (%)	Consum. equiv. (%)
Baseline economy with optimal replacement rate (51%)	0	0
Age-dependent replacement rate	23.3	0.8
Age-dependent tax rate	68.3	2.4
Age-dependent replacement rate and tax rate	92.4	3.2
First best economy	100.0	3.4

income replacement rates are maintained at the current US level and labor income tax rates are allowed to vary with age. In this economy, tax rates are implicitly set to smooth the age profile of income, so consumption is relatively smooth over the life cycle but not across employment states. The economy with age-dependent income tax rates yields welfare gains equivalent to about two-thirds of those under the combined age-dependent policy for replacement rates and taxes, with the uncovered one third due to age-dependent income replacement rates. As is discussed below, a good part of the welfare gain comes from relaxing financial constraints over the life cycle: in the baseline economy of Section 4.3, when we set the borrowing limit l at its natural level—so that no worker is financially constrained—welfare increases by around 3% in consumption equivalent, a large share of the gains from age-dependent policies.[27]

Decomposing welfare gains The welfare gains stem from five different first-order effects: better consumption smoothing over the life cycle, better consumption smoothing across employment states, a lower incidence of unemployment, a changing allocation of search effort, and finally production efficiency, insofar as output increases. Production efficiency gains are equal to the expected increase

[26] As in Shimer and Werning (2008), there is small welfare gain from making UI benefits dependent on unemployment duration. As workers spend more time unemployed, their assets as well as their human capital fall, which drives their consumption down. This gives unemployed workers close-to-optimal incentives to search for new jobs.

[27] Notice that the natural borrowing limit is function of worker's age n and workers's human capital e, $l(n, e)$, see the Online Appendix for details.

in the present value of output produced by a worker at birth. To measure the contribution of the other four effects, we take the expected initial utility of a fictional worker representative of a given economy, up to first order effects. Second order effects due to changes in the dispersion of consumption and search effort are measured as residuals. The representative worker is active in the labor market for $\bar{n}_w$ periods and retired for the remaining $\bar{n}_r$ periods of his life. At each age n the worker has a probability ν_n of being unemployed, equal to the age-specific unemployment rate in the economy. If employed, he has consumption c_n equal to the analogous economy-wide average. If unemployed, his consumption level is $c_n(1-\varphi_n)$, where φ_n denotes the average consumption loss upon unemployment at age n in the economy. The mass of people searching is $\frac{\delta_n}{1-(1-\delta_n)\overline{\mu}_n}$ and the within-period unemployment probability is $\overline{\mu}_n = 1 - f_n$, equal to the average probability of remaining unemployed for a worker searching for a job at age n. The initial utility of the representative worker is set equal to $\mathrm{UR}(\widetilde{c}, \widetilde{\varphi}, \widetilde{\nu}, \widetilde{\mu}) = \sum_{n=1}^{\bar{n}_w+\bar{n}_r} \beta^{n-1} \left[(1-\nu_n)\, u(c_n) + \nu_n u(c_n(1-\varphi_n)) + \frac{\delta_n \psi(\overline{\mu}_n)}{1-(1-\delta_n)\overline{\mu}_n}\right]$ which is a function of the sequence of consumption $\widetilde{c}$, of consumption losses upon unemployment $\widetilde{\varphi}$, of the incidence of unemployment $\widetilde{\nu}$, and of within-period unemployment probabilities $\widetilde{\mu}$. The last term in square brackets is set to zero for $n > \bar{n}_w$. We checked that UR approximates the initial utility of the corresponding economy reasonably well. This is because, after conditioning for age, cross sectional heterogeneity in consumption and search effort is relatively small. We calculate UR in the baseline economy and then measure how it varies when replacing (one at a time) $\widetilde{c}$, $\widetilde{\varphi}$, $\widetilde{\nu}$, and $\widetilde{\mu}$ of the baseline economy with the corresponding values for the economy with age-dependent policies. This measures the gains from better consumption smoothing over life cycle, from better consumption smoothing across employment states, from lower incidence of unemployment, and from changing search effort, respectively. The sequence of consumption $\widetilde{c}$ from the economy with age-dependent policies is scaled down by the size of the production efficiency gains. The measures of gains are converted into equivalent consumption units and correspond to percentage increases. The resulting gains are reported in Table 7 both for the economy with age-dependent benefits only (column 2) and for the economy where both taxes and benefits are age-dependent (column 3). In the economy with age-dependent benefits only, most gains come from better consumption smoothing across employment states. In the economy with age-dependent benefits and taxes, there are also important gains from smoothing consumption over the life cycle, which represent almost a 2% increase in life time

Table 7: Decomposing welfare gains of age-dependent policies

Source of gain	Age-dependent benefits only	Age-dependent benefits and taxes
Production efficiency	0.05	0.58
Consumption smoothing over time	0.11	1.55
Consumption smoothing across states	0.46	1.07
Incidence of unemployment	0.12	0.27
Search effort over time	-0.06	-0.35
Sum	0.68	3.07
Residual (second order effects)	0.10	0.11
Total	0.78	3.18

Notes: Equivalent consumption percentage increases relative to the baseline economy.

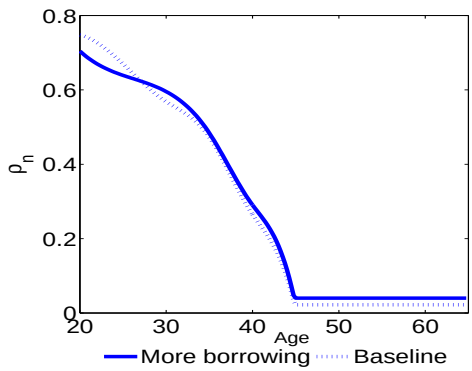
consumption. These gains are smaller, but still present even in the economy with age-dependent benefits only, because young workers use their high UI replacement rates to obtain a smoother consumption profile over the life cycle. As is discussed below the magnitude of these gains is affected by the financial constraint l. The contribution of the changing allocation of leisure is negative, since average search effort in the economy increases.

7 Further discussion

Now let examine the robustness of the result that UI income replacement rates should generally decrease with age to alternative specifications of the baseline model. We first study the effects of relaxing the borrowing constraint l, and then analyze the effects of changing the return to skill. We also consider a version of the model in which the government budget constraint (24) is age-specific, barring income redistribution across age groups. Then we study the role of age-dependent severance payments in insuring workers against unemployment risk over the life cycle. Finally we consider larger wage losses during unemployment $\overline{\kappa}_n$. In analyzing the alternative specifications, we always re-calibrate the economy to hit exactly the same targets in Section 4.3.

7.1 Relaxing the borrowing limit

To study the effects of relaxing the borrowing constraint l, we multiply its value by a factor of three—so we now have $l = -3.36$. The solid line in Figure 11 shows the new optimal profile of age-dependent UI income replacement rates in the economy with constant income tax rates. The replacement rates basically duplicate the profile of the age-dependent policy version of the baseline economy, but they are



Notes: Profile of UI income replacement rates in the economy with optimal age-dependent replacement rates and constant income tax rates. Solid line corresponds to the economy with relaxed borrowing constraint, dotted line to baseline economy.

Figure 11: Age-dependent UI income replacement rates with relaxed borrowing constraints

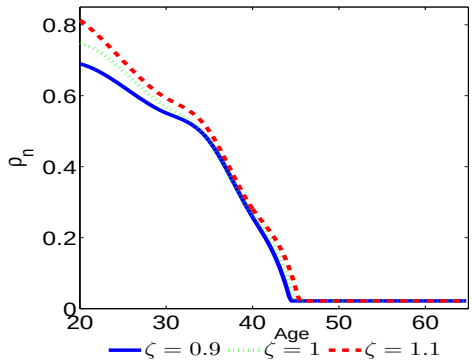
lower for young workers, who are now less financially constrained. We have also studied the welfare gains of optimally choosing age-dependent replacement and tax rates, which diminishes now to a 2.2% increase in consumption by comparison with the economy with an optimal constant replacement rate—which now becomes 48%. This confirms that in our model a substantial part of the welfare gains from age-dependent policies stem from relaxing financial constraints.

7.2 Changing the return to experience

The return to labor market experience varies significantly by type of workers. For example, wage increases over the life cycle are substantially greater for college than for high school graduates: roughly speaking the former attain an increase that is 20 percent more than in our baseline economy, the latter 20 percent less. To analyze the sensitivity of our results to changes in the return to skill, we take the experience function $w(e)$ with the normalization condition $w(0) = 1$ and set the values of the spline at all age knots to $1 + \zeta\,[w(e) - 1]$. The constant $\zeta - 1$ represents a percentage change in the return to labor market experience. We then analyze the optimal age profile of UI income replacement rates in two economies one with $\zeta = .9$ and another with $\zeta = 1.1$ (about a 20% difference in the return to experience). This offers preliminary evidence on how the age profile should change with education.[28] We find that the results change very little: there are

[28]Of course, one should be careful in taking education as exogenous, since the return to education and hence the incentive for it is itself affected by labor market institutions. To be

always welfare gains from allowing UI income replacement rates to decrease with age, while the profile of replacements rates is also similar across groups (Figure 12). But notice that a fall in the return to experience produces a flatter age profile and smaller welfare gains. When the return to experience falls, the government can insure young workers less because the moral hazard problem is more severe. Moreover, with lower returns to experience, younger workers are less financially constrained and value unemployment insurance less highly.



Notes: Profile of UI replacement rates in the economy with optimal age-dependent UI replacement rates and constant income tax rates. Dotted lines correspond to the baseline economy, other lines correspond to economy with lower $\zeta = .9$ (as a solid line) and higher $\zeta = 1.1$ (as a dashed line) return to experience.

Figure 12: Age-dependent UI replacement rates and the return to experience

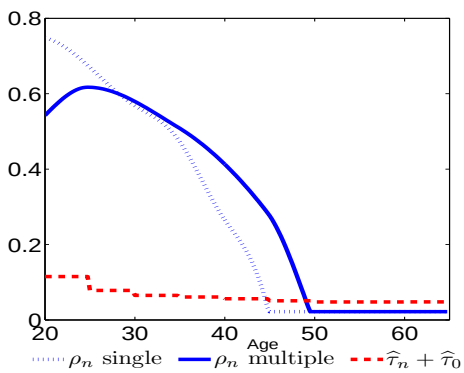
7.3 Age-dependent government budget constraints

The budget constraint in (24) implies that part of the welfare gains from age dependent benefits comes because some tax revenue is redistributed from older wealthier workers to younger less wealthy ones. We now show that this is not the main reason why replacement rates should decrease with age, studying an economy where benefit expenditures for workers of a given age are financed by taxes levied just on workers of the same age (no tax revenue redistribution across age groups).[29] We divide the population into N mutually exclusive age groups with maximum age difference $k = 20$ within the group, so that $Nk = \bar{n}_w$. The set of age levels for the ith age group, $i = 1, 2...., N$, is given by $\Gamma_i = \{(i-1)k + 1, (i-1)k + 2...., ik\}$. Income taxes are the sum of two rates, one used to finance

sure, here we are not advocating that UI income replacement rates should be education specific.

[29] We are thankful to Emmanuel Farhi, Juan Pablo Nicolini, and Robert Shimer for suggesting us this exercise.

benefits for the specific age group denoted by $\overline{\tau}_n$, the other to finance retirement pensions, denoted by $\hat{\tau}_0$. So we have $\tau_n = \overline{\tau}_n + \hat{\tau}_0$ (see the Online Appendix for details). We then search for the age profile of the UI income replacement rate $\rho \geq 0$ that maximizes the worker's initial wealth W_s subject to the same constraints as before but where now the tax rates $\hat{\tau}_i$'s $i = 1, ..., N$ satisfy the N age-specific government budget constraints while $\hat{\tau}_0$ is set to finance pensions. The resulting optimal age-dependent replacement rate under the age-specific budget constraints corresponds to the solid line in Figure 13. For comparison, the optimal age-dependent replacement rate from Figure 8 is also plotted (dotted line). The replacement rate is again generally decreasing in age (at least for workers over 25), but, as no intergenerational redistribution is allowed, the age profile is now marginally flatter.



Notes: The age-specific budget constraint is satisfied for non-overlapping age groups of five years. Solid line is the age profile of replacement rates, dashed line that of income tax rates. Dotted line corresponds to the optimal profile of UI income replacement rates in Figure 8.

Figure 13: Age-dependent replacement rate with age-specific budget constraint

7.4 Severance payments

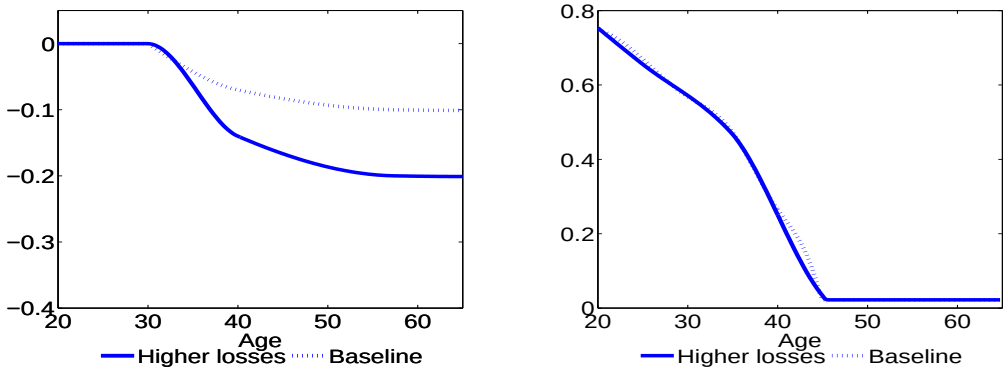
To insure workers against wage loss upon displacement, it might be useful to include severance pay in the optimal unemployment insurance package. Here we show that age variation in severance payments helps little in enhance welfare compared with the economy with optimal age-dependent benefits and taxes. To do so, we now allow for age-dependent severance payments: upon job displacement workers receive a government transfer equal to $\varsigma_n w(e)$ (age n and human capital e here refer to the last period before job displacement). All the other assumptions of the baseline model remain as in Section 4. We keep the profiles of age-dependent

benefits and taxes as given. To be sure, let ρ_n^* and τ_n^* denote the optimal age profile of benefits and taxes as in Figure 10. Here we assume that $\rho_n = \rho_n^*$ and $\tau_n = \tau_n^* + \overline{\tau}$, where $\overline{\tau}$ is needed to to satisfy the budget constraint. We then search for the vectors of severance payments $\varsigma = \{\varsigma_1, ..., \varsigma_{\overline{n}_w}\}$ and the value of the tax rate $\overline{\tau}$ that maximize worker's initial utility $W_s \equiv J(1, 0, 0)$ subject to the new budget constraint (see the Online Appendix for details). Exactly as in Section 6, we assume that ς_n is a cubic spline at the previously defined ten age knots and search for the value at the knots that maximize W_s. When severance payments are independent of age $\varsigma_n = \varsigma$, $\forall n$, the optimal constant over age severance payment is $\varsigma = 1.4$. This economy yields welfare gains equivalent to a 3.3% increase in life time consumption relative to the baseline economy. This is 0.1 percentage point more than in the economy with optimal age-dependent benefits and taxes. If severance pay varies with age, we find virtually no additional gains (up to the fourth order).

7.5 Wage losses during unemployment

In the Online Appendix we compare earnings losses upon displacement in our model with estimates from the empirical literature (Stevens 1997, Couch and Placzek 2010, Davis and von Wachter, 2011) and other theoretical models (Jung and Kuhn 2012). In our baseline calibration, the model tends to underestimate earning losses upon displacement, especially in the long term (more than three years after displacement); losses in the model are around half those in the empirical data. We accordingly analyze the robustness of our results when the wage loss during unemployment $\overline{\kappa}_n - 1$ is doubled. The new age profile of $\overline{\kappa}_n - 1$ is plotted in panel (a) of Figure 14, the new optimal age-dependent UI income replacement rate ρ_n in panel (b). Solid lines correspond to the new specification, dotted lines correspond to baseline. It is apparent that the profile of the optimal age-dependent ρ_n is virtually unchanged compared to the baseline calibration. As discussed in the Online Appendix, this is a general property of the model: the optimal age profile of ρ_n is very little affected by changes in either the level or the age profile of $\overline{\kappa}_n$.[30]

[30] In practice this happens because the age profile of the extended redistribution formula $\widetilde{\varrho}$ changes little in response to changes in the profile of $\overline{\kappa}_n$. For example, with a lower $\overline{\kappa}_n$, the marginal utility of consumption of the unemployed goes up which pushes up the value of the numerator of $\widetilde{\varrho}$. But the lower $\overline{\kappa}_n$ also makes tax effects more important, so $-\frac{\partial T}{\partial b_n}$ goes up, which increases the denominator of $\widetilde{\varrho}$ and on balance leaves the overall profile of $\widetilde{\varrho}$ unchanged.



(a) Wage losses: $\overline{\kappa}_n - 1$

(b) Replacement rates, ρ_n

Notes: Panel (a) plots the age profile of wage losses during unemployment in the baseline calibration (dotted line) and in the economy where wage losses are doubled (solid line). Panel (b) plots the optimal age-dependent UI income replacement rate ρ_n in the two economies.

Figure 14: Age-dependent UI income replacement rates and wage losses upon re-employment

8 Conclusion

Unemployed young workers have a high marginal utility of consumption, suffer large consumption losses upon unemployment, and respond little to changes in unemployment benefits. This indicates that they value unemployment insurance highly, while the problem of moral hazard is mild. Using a life cycle model with unemployment risk and endogenous search effort, we find that under the optimal age-dependent policy, income replacement rates should increase from the current level of 50 per cent to around 80 percent for workers in their mid-twenties and 60 per cent for those in their thirties. Workers in their forties and fifties, instead, get benefits of less than 10 percent of their last wage. Allowing unemployment benefit replacement rates and other government transfers to decline with age yields sizeable welfare gains that amount to around 90 percent of the gains attained under the unconstrained optimal scheme for unemployment insurance over the life cycle. Around a quarter of these gains are due to age dependent unemployment benefits. The quantitative analysis also shows that the age variation in the ratio of the marginal utility of consumption when unemployed to one plus the elasticity of unemployment to benefits closely identifies the existence of welfare gains from redistributing unemployment insurance over the life cycle. This simple ratio neglects the effects of age-specific changes in benefits on tax revenue and

on unemployment among age groups not directly targeted by the policy change. Incorporating these effects leads to an extended redistribution formula that works exactly in our quantitative model and that might prove to be substantially more accurate than the previously discussed simple ratio in other attempts of identifying the gains from redistributing benefits across workers of different age, gender, or race.

We purposely simplified the theoretical analysis in some ways. For example, we have assumed that job separation rates are exogenous, while in practice UI benefits affect the outside options of employed workers which can lead to higher separation rates and more occupational mobility, which we know (Kambourov and Manovskii 2008, 2009) are higher for the young than for the old. Our modeling of wage losses upon displacement also assumes the depreciation of human capital during unemployment, but in practice workers could have accumulated job-specific human capital that is immediately lost upon displacement regardless of the duration of unemployment. Allowing for job-specific human capital could weaken our conclusion that age-dependent severance payments do little towards achieving the welfare gains obtained under the optimal program. Still, we believe that our results on the optimal age profile of UI benefits are robust to alternative modeling choices for the process that leads to wage loss upon displacement.

Our analysis suggests that age-dependent policies are Pareto-improving when applied solely to new generations of workers entering the labor market, but as policy reforms cannot ordinarily be applied to specific cohorts, the introduction of age-dependent labor market institutions might have to deal with important redistribution concerns. In studying age-dependent labor market institutions, we have focused only on the amount of unemployment benefits, but the analysis could well be extended to other features, such as benefit duration, maximum benefit level, and eligibility as well as to other labor market institutions, such as employment protection and poverty programs. Along some of these dimensions it could well turn out that older workers require more protection than younger workers.

Future research should also evaluate the welfare gains from age-dependent policies for unemployment insurance programs different from those currently in place in the US. In particular Feldstein and Altman (1998) and Feldstein (2005) have advocated individual saving accounts to attenuate the moral hazard implicit in unemployment insurance. The concept is that the employed worker saves a fraction of his earnings in an individual saving account which he draws on when

unemployed to receive the benefit payments dictated by the current US unemployment system. At retirement, any residual positive balance is transferred back to the worker. The quantitative welfare gains of saving accounts systems have been studied by Ferrada (2010), Setty (2010), and Pallage and Zimmermann (2010). Our robustness exercise shows that replacement rates should decline with age also when workers face a loose borrowing constraint. Since savings accounts are essentially a means of providing greater liquidity to unemployed workers, this suggests that welfare gains should accrue from having unemployment insurance income replacement rates decrease with age also in plausible implementation of the saving account proposal. This squares with the conclusions of Setty (2010), who introduced elements favoring younger workers in his proposed implementation of the savings account system.

References

Acemoglu, Daron, and Robert Shimer. 2001. "Efficient Unemployment Insurance." *Journal of Political Economy*, 107(5): 893–928.

Akerlof, George. 1978. "The Economics of 'Tagging' as Applied to the Optimal Income Tax, Welfare Programs, and Manpower Planning." *American Economic Review*, 68(1): 8–19.

Autor, David, David Dorn, Gordon Hanson, and Jae Song. 2013. "Trade Adjustment: Worker Level Evidence." NBER Working Paper 19226.

Baily, Martin Neil. 1978. "Some aspects of optimal unemployment insurance." *Journal of Public Economics*, 10(3): 379–402.

Bloemen, Hans, and Elena Stancanelli. 2005. "Financial Wealth, Consumption Smoothing, and Income Shocks due to Job Loss." *Economica*, 72(3): 431–452.

Blundell, Richard, Luigi Pistaferri, and Ian Preston. 2008. "Consumption Inequality and Partial Insurance." *American Economic Review*, 98(5): 1887–1921.

Browning, Martin, and Thomas Crossley. 2001. "Unemployment Insurance Benefit Levels and Consumption Changes." *Journal of Public Economics*, 80(1): 1–23.

Chéron, Arnaud, Jean-Olivier Hairault, and Francois Langot. 2012. "Life-Cycle Equilibrium Unemployment." *Journal of Labor Economics*, forthcoming.

Chéron, Arnaud, Jean-Olivier Hairault, and Franois Langot. 2011. "Age-Dependent Employment Protection." *Economic Journal*, 121(557): 1477–1504.

Chetty, Raj. 2006. "A general formula for the optimal level of social insurance." *Journal of Public Economics*, 90(10-11): 1879–1901.

Chetty, Raj. 2008. "Moral Hazard versus Liquidity and Optimal Unemployment Insurance." *Journal of Political Economy*, 116(2): 173–234.

Conesa, Juan Carlos, Sagiri Kitao, and Dirk Krueger. 2009. "Taxing Capital? Not a Bad Idea After All!" *American Economic Review*, 99(1): 25–48.

Couch, Kenneth, and Dana Placzek. 2010. "Earnings Losses of Displaced Workers Revisited." *American Economic Review*, 100(1): 572–89.

Cullen, Julie Berry, and Jonathan Gruber. 2000. "Does Unemployment Insurance Crowd Out Spousal Labor Supply?" *Journal of Labor Economics*, 18(3): 546–72.

Davidson, Carl, and Stephen Woodbury. 1997. "Optimal unemployment insurance." *Journal of Public Economics*, 64(3): 359–387.

Davis, Steven, and Till von Wachter. 2011. "Recessions and the Costs of Job Loss." *Brookings Papers on Economic Activity, Economic Studies Program*, 43(2): 1–72.

Erosa, Andres, and Martin Gervais. 2002. "Optimal Taxation in Life-Cycle Economies." *Journal of Economic Theory*, 105(2): 338–369.

Farhi, Emmanuel, and Iván Werning. 2013. "Insurance and Taxation over the Life Cycle." *Review of Economic Studies*, 810(2): 596–635.

Feldstein, Martin. 2005. "Rethinking Social Insurance." *American Economic Review*, 95(1): 1–24.

Feldstein, Martin, and Daniel Altman. 1998. "Unemployment Insurance Savings Accounts." National Bureau of Economic Research Working paper 6860.

Ferrada, Christian. 2010. "Individual Savings Accounts in Chile: Income vs. Substitution Effects and Saving Responses." Manuscript, Chicago University.

Gervais, Martin. 2004. "On the Optimality of Age-Dependent Taxes and the Progressive US Tax System." University of Southhampton Manuscript.

Gorry, Aspen, and Ezra Oberfield. 2012. "Optimal Taxation over the Life Cycle." *Review of Economic Dynamics*, 15(4): 551–572.

Gouriéroux, Christian, Alain Monfort, and Eric Renault. 1993. "Indirect Inference." *Journal of Applied Econometrics*, 8: S85–S118.

Gritz, Mark, and Thomas MaCurdy. 1992. "Unemployment Compensation and Episodes of Nonemployment." *Empirical Economics*, 17: 183–204.

Gruber, Jonathan. 1997. "The Consumption Smoothing Benefits of Unemployment Insurance." *American Economic Review*, 87(1): 192–205.

Hopenhayn, Hugo, and Juan-Pablo Nicolini. 1997. "Optimal Unemployment Insurance." *Journal of Political Economy*, 105(2): 412–38.

Hopenhayn, Hugo, and Juan-Pablo Nicolini. 2009. "Optimal Unemployment Insurance and Employment History." *Review of Economic Studies*, 76(3): 1049–1070.

Hryshko, Dmytro, Maria-Jose Luengo-Prado, and Bent Sorensen. 2010. "House Prices and Risk Sharing." *Journal of Monetary Economics*, 57(8): 975–987.

Jacobson, Louis, Robert LaLonde, and Daniel Sullivan. 1993. "Earnings Losses of Displaced Workers." *American Economic Review*, 83(4): 685–709.

Johnson, Richard, and Corina Mommaerts. 2011. "Age Differences in Job Loss, Job Search, and Reemployment." The Urban Institute Working Paper 11-01.

Jung, Philip, and Moritz Kuhn. 2012. "Earnings losses and labor mobility over the life-cycle." Mimeo, University of Bonn.

Kambourov, Gueorgui, and Iourii Manovskii. 2008. "Rising occupational and industry mobility in the United States: 1968-97." *International Economic Review*, 49(1): 41–79.

Kambourov, Gueorgui, and Iourii Manovskii. 2009. "Occupational specificity of human capital." *International Economic Review*, 50(1): 63–115.

Koehne, Sebastian, and Moritz Kuhn. 2014. "Should unemployment insurance be asset-tested?" Mimeo, Institute for International Economic Studies and University of Bonn.

Kremer, Michael. 2001. "Should Taxes be Independent of Age?" Harvard University Manuscript.

Krueger, Alan, and Andreas Mueller. 2010. "Job Search and Unemployment Insurance: New Evidence from Time Use Data." *Journal of Public Economics*, 94(3-4): 298–307.

Lentz, Rasmus, and Torben Tranaes. 2005. "Job Search and Savings: Wealth Effects and Duration Dependence." *Journal of Labor Economics*, 23(3): 467–490.

Menzio, Guido, and Shouyong Shi. 2011. "Efficient Search on the Job and the Business Cycle." *Journal of Political Economy*, 119(3): 468–510.

Meyer, Bruce, and Wallace Mok. 2007. "Quasi-Experimental Evidence on the Effects of Unemployment Insurance from New York State." NBER Working Paper 12865.

Mirrlees, James, Stuart Adam, Timothy Besley, Richard Blundell, Stephen Bond, Robert Chote, Malcolm Gammie, Paul Johnson, Gareth Myles, and James Poterba, ed. 2010. *Dimensions of Tax Design: the Mirrlees Review.* Oxford University Press.

Moen, Espen. 1997. "Competitive Search Equilibrium." *Journal of Political Economy*, 105(2): 385–411.

Mortensen, Dale, and Christopher Pissarides. 1994. "Job Creation and Job Destruction in the Theory of Unemployment." *Review of Economic Studies*, 61(3): 397–415.

Mueller, Andreas. 2010. "Separations, Sorting and Cyclical Unemployment." IIES Manuscript.

OECD. 2007. *Pensions at a glance.* OECD.

Pallage, Stephane, and Christian Zimmermann. 2010. "Unemployment Benefits vs. Unemployment Accounts: A Quantitative Exploration." Federal Reserve Bank of St-Louis Manuscript.

Pavoni, Nicola. 2007. "On Optimal Unemployment Compensation." *Journal of Monetary Economics*, 54(6): 1612–1630.

Pavoni, Nicola. 2009. "Optimal Unemployment Insurance, with Human Capital Depreciation, and Duration Dependence." *International Economic Review*, 50(2): 323–362.

Pavoni, Nicola, and Giovanni Violante. 2007. "Optimal Welfare-to-Work Programs." *Review of Economic Studies*, 74(6): 283–318.

Pavoni, Nicola, Ofer Setty, and Giovanni Violante. 2010. "Search and Work in Optimal Welfare Programs." Manuscript, New York University and Tel Aviv University.

Pissarides, Christopher. 2000. *Equilibrium Unemployment Theory.* . Second ed., Cambridge, MA: MIT Press.

Rendahl, Pontus. 2012. "Asset Based Unemployment Insurance." *International Economic Review*, 53(3): 743–770.

Ruggles, Steven, J. Trent Alexander, Katie Genadek, Ronald Goeken, Matthew Schroeder, and Matthew Sobek. 2010. "Integrated Public Use Microdata Series: Version 5.0." Minneapolis, MN: Minnesota Population Center.

Setty, Ofer. 2010. "Unemployment Accounts." Manuscript, Tel Aviv University.

Shimer, Robert. 2005. "The Assignment of Workers to Jobs in an Economy with Coordination Frictions." *Journal of Political Economy*, 113(5): 996–1025.

Shimer, Robert, and Iván Werning. 2007. "Reservation Wages and Unemployment Insurance." *Quarterly Journal of Economics*, 122(3): 1145–1185.

Shimer, Robert, and Iván Werning. 2008. "Liquidity and Insurance for the Unemployed." *American Economic Review*, 98(5): 1922–1942.

Stevens, Ann Huff. 1997. "Persistent Effects of Job Displacement: The Importance of Multiple Job Losses." *Journal of Labor Economics*, 15(1): 165–88.

Stokey, Nancy, Robert Lucas, and Edward Prescott. 1989. *Recursive Methods in Economic Dynamics.* Harvard University Press.

Sullivan, Jim. 2008. "Borrowing During Unemployment: Unsecured Debt as a Safety Net." *Journal of Human Resources*, 43(2): 383–412.

Weinzierl, Matthew. 2011. "The Surprising Power of Age-Dependent Taxes." *Review of Economic Studies*, 78(4): 1490–1518.

Online Appendix for the paper "Optimal Life Cycle Unemployment Insurance"

Claudio Michelacci and Hernán Ruffo

APPENDIX

Section A describes the data, Section B extends the analysis of the model in Section 2 and derives the extended redistribution formula discussed in Section 2.3, Section C discusses computational details, Section D discusses the properties of the models in terms of earning losses upon displacement, Section E discusses further details about the robustness section (Section 7).

A Data appendix

We describe the data from SIPP, CPS, PSID, Mathematica, and SCF used in the paper.

A.1 The SIPP

The data from the Survey of Income and Program Participation (SIPP) is obtained from Chetty (2008) and Johnson and Mommaerts (2011) and they are constructed starting from the 1985, 1986, 1987, 1990, 1991, 1992, 1993, 1996, 2001, and 2004 panels of SIPP. Interviews were conducted every four months for a period of two to four years. As in Chetty (2008), the analysis on unemployment duration uses data that span the beginning of 1985 to the middle of 2000. The original sample is restricted to those male workers between 18 and 65 years of age with an unemployment spell, with at least three months of work history, that reported non-zero unemployment duration, that actively search for a job, that were not temporary layoffs and that received UI benefits in the first month of the unemployment spell, from all states but Maine, Vermont, Iowa, North Dakota, South Dakota, Alaska, Idaho, Montana and Wyoming since SIPP does not provide a unique identifiers for these small states. The final sample covers 4560 unemployment spells, see the Appendix in Chetty (2008) for further details. The analysis on wage losses span the years 1996 to 2007, covering the 2001 recession but not the 2007-2009 recession. As in Johnson and Mommaerts (2011), we do not use earlier panels because they lack detailed information on why respondents separate from their jobs, which we use to separately identify quits from layoffs. The original sample is restricted to those male white workers between 18 and 65 years of age who work full time (at least thirty hours per week in their main job), who are displaced and who have collected UI benefits at some point during their unemployment spell. We exclude self-employed workers. Respondents enter the sample when first displaced from a job at which they had been working for at least two months and they remain in the sample until they first find a new full time job that lasts for at least one month. To focus on displacement for exogenous reasons, we classify respondents as displaced if they report separating from their employer because of layoff, slack

work, employer bankruptcy, or because the employer sold the business. We include in the sample only the first unemployment spell for each worker. Below we describe in more details the variables used in the paper.

Age This is equal to the age of workers measured in years, which corresponds to variable TAGE in the survey.

Age specific average benefits level These are calculated exactly as in the CPS analysis below, see Section A.2.

Average benefits This is the average benefits in each state and year provided by the Department of Labor.

Marital status This is a dummy variable which is equal to one if the individual is currently married. This is constructed using variable EMS which can take the following values: 1. Married, spouse present; 2. Married, spouse absent; 3. Widowed; 4. Divorced; 5. Separated; 6. Never married. An individual is classified as married if he reports EMS=1 or EMS=2.

Individual UI benefits We use the imputation by Chetty (2008) who is based on estimating a first-stage equation for earnings using OLS on the full sample of individuals who report a job loss at some point during the sample period. He regresses nominal log wages in the year before job loss on years of education, age at job loss, years of tenure on the last job, a dummy for left-censoring of this job tenure variable, industry, occupation, month, and year dummies, and the unemployment rate in the relevant state/year. Using the coefficient estimates, he predicts log wages for each job loser, and recover the predicted wage in levels. He then uses the predicted wage to simulate the claimant unemployment benefit using the UI benefit calculator by Cullen and Gruber (2000).

Earnings losses Earnings losses upon displacement are calculated as the percentage differences between the value of monthly labor earnings in the job before displacement and the value of monthly earnings in the new job after reemployment.

Monthly labor earnings This is constructed using variable TPMSUM in the survey that reports total earnings from job before deductions received in the month of the survey.

Previous job tenure This variable is constructed using variable TSJDATE in the survey, which reports the year/month when the current job has started.

Unemployment duration SIPP reports the employment status of individuals for every week that they are in the sample. Weekly employment status (ES) can take the following values: 1. With a job this week; 2. With a job, absent without pay, no time on layoff this week; 3. With a job, absent without pay, spent time on

layoff this week; 4. Looking for a job this week; 5. Without a job, not looking for a job, not on layoff. A job separation is defined as a change in ES from 1 or 2 to 3, 4, or 5. As in Cullen and Gruber (2000), unemployment duration is obtained by summing the number of consecutive weeks with ES ≥ 3, starting at the date of job separation and stopping when the individual finds a job that lasts for at least one month (i.e., reports a string of four consecutive ES=1 or ES =2). Individuals are defined as being on temporary layoff if, at any point in the spell, they report ES = 3. They are defined as searching if they report ES = 4.

Job finding probability at unemployment duration This is constructed using the weekly employment status variable ES described above and corresponds to a transition from ES=4 to a string of four consecutive ES=1 or ES=2.

Year This is a dummy that identifies the year of the interview.

Years of education This is simply constructed using variable HIGRADE in the survey, which reports the highest grade or year of school attended.

Worker's wealth Asset data are generally collected only once in each panel, so pre-unemployment asset data is available for approximately half of the observations. Total net wealth is defined as values of stocks, bonds, savings and current accounts plus the value of properties, business and vehicle equities net of secured and unsecured debt. The values of assets and liabilities are constructed using answers to several questions that report the individually reported estimate of the average amount that husband and wife jointly hold in a specific asset or liability over the four months period preceding the date of the interview.

Worker's net liquid wealth is measured at the time of job loss as total wealth minus home, business and vehicle equity net of unsecured debt (which is equal to the amount owed by the household, excluding mortgages and vehicle loans). The variable is again constructed using answers to several questions that report the individually reported estimate of the average amount that husband and wife jointly hold in a specific asset or liability over the four months period preceding the date of the interview.

Displaced workers Wage losses upon re-employment are used as a calibration target, see Table 4. These are calculated by focusing on a sample of displaced workers. Displaced workers are identified using the variable ERSEND which report the "Main reason why the individual stopped working for employer". The variable ERSEND can take the following values: 1 . On Layoff; 2. Retirement or old age; 3. Childcare problems; 4. Other family/personal obligations; 5. Own illness; 6. Own injury; 7. School/Training; 8. Discharged/fired; 9. Employer bankrupt; 10. Employer sold business; 11. Job was temporary and ended; 12. Quit to take another job; 13. Slack work or business conditions; 14. Unsatis-

factory work arrangements (hours, pay, etc); 15. Quit for some other reason. Individuals are classified as displaced if they stopped working for the employer and they report ERSEND=1, 8, 9, or 10.

Hours This is constructed using the variable EJBHRS that report "How many hours per week the worker usually works at all activities at his main job".

Table A1 gives summary statistics for the core sample and for two different age groups: workers of age from 20 to 40 years and from 40 to 60 years. Monetary

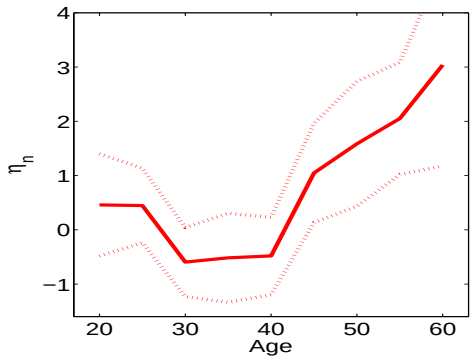
Table A1: Summary Statistics, SIPP sample

Variable	*All*	*20-40 years*	*41-60 years*
Mean Annual wage	20711.27	18699.21	24665.52
Median Annual Wage	17780.48	16512.12	21745.91
Years of education	12.1	12.1	12.2
Weekly indiv UI benefits	165.72	153.30	187.87
Mean unemp. duration	20.45	18.90	22.68
Median unemp. duration	15.00	14.00	17.00
Mean liquid assets	22545.31	14897.08	34086.46
Mean net liquid assets	18583.77	11044.50	29902.03
Mean total wealth	62705.52	44955.76	90015.60
Percent with Mortgage	.45	.40	.54
Quartile of net liquid assets:			
Q_1	-2177.89	-2231.28	-2081.14
Q_2	-54.92	-63.28	-42.43
Q_3	919.15	911.81	948.12
Q_4	19897.43	12427.25	31077.48
Observations	4560	2873	1536

values are in 1990 dollars converted using the CPI index. The median UI benefits recipient is a high school graduate and has pre-UI gross annual earnings of 20,711. The group of workers with 20 to 40 years of age has 2873 observations, the group of workers with 41 to 60 years of age has 1522 observations. Mean unemployment duration is 20 weeks for the whole sample. Unemployment spells for workers with more than 40 years of age are 4 weeks longer than the analogous spells for workers with less than 40 years of age. The individually imputed UI benefit level (in 1990 dollars) is around 20% higher for the old than for the young. This difference is explained by the fact that mean pre-unemployment wage is 30% higher for the old. The resulting average replacement rate is therefore lower for the old workers than for the young.

A.2 Aggregate US states data using CPS

Aggregate US states data are calculated using monthly data from the Current Population Survey databases freely available from Integrated Public Use Microdata Series (IPUMS), see Ruggles et al. (2010) for description of IPUMS. Information



(a) Micro-evidence, SIPP

Notes: Elasticity of unemployment to benefits for different age groups of workers. Estimates are based on model (14) using SIPP data and the age-specific average measure of benefits. Other details are as for panel (a) in Figure 1.

Figure A1: Elasticity of unemployment to benefits by age group: age-specific average measure of UI benefits, SIPP

on labor force, employment, unemployment, and other demographic and labor force characteristics is available in every month, while earnings data are available in the March survey. We restrict the sample to male workers with 16 to 64 years of age. Similar to SIPP the sample period is 1984-2000. For each state, semester and age group we aggregate individual data using CPS provided weights. Below we describe more in detail the variables used in the analysis.

Pre-unemployment wage: It is imputed at the individual level after running a conventional wage regression in each state and year using the March CPS survey. The dependent variable in the wage regression is weekly logged wages and the independent variables are a quadratic polynomial in age, four educational dummies (for high school dropouts, high school degree, some college and complete college), two race dummies and a marital status dummy. Using the estimated coefficients we impute wage to every unemployed worker. Weekly wages are computed using the variable EARNWEEK in IPUMS which reports information on "usual labor earnings per week at the current job, before deductions".

Age specific average benefits level We impute benefits at the individual level using the UI benefit calculator by Cullen and Gruber (2000). As an input we use the individual imputation for pre-unemployment wages calculated above. In three states, the UI benefits calculator requires previous job tenure as an input. For these states, we impute tenure using a quadratic function of age which we estimate using the Mathematica data below. Individual benefits are then aggregated to obtain a measure of average benefits for each age group in a given semester and given state. Average benefits are always adjusted to guarantee equality with the

unconditional average benefits measure in each state and year as reported by the US Department of Labor. In all regressions, the age groups considered for constructing the age specific average measure of benefits always coincide with the age groups for which we calculate the age-specific elasticity of unemployment to benefits.

Educational composition We construct five educational dummies using information obtained from the variable EDUC in IPUMS which corresponds to answers to the following question: "What is the highest level of school (name/you) (have/has) completed or the highest degree (name/you) (have/has) received?". We use this information to construct the following five educational groups: (i) less than 5 grade; (ii) 5th grade to 12th grade without diploma; (iii) High school diploma; (iv) some college or vocational program but no degree; (v) Bachelor's degree or more.

Race composition We construct a dummy variable that is one if worker is white, as inferred from the answer to "I am going to read you a list of five race categories. Please choose one or more races that (NAME/you) (considers yourself/consider NAME/considers himself/considers herself) to be: White; Black or African American; American Indian or Alaska Native; Asian; OR Native Hawaiian or Other Pacific Islander". Starting from this information we calculate the proportion of white unemployed workers in each state, period and age group.

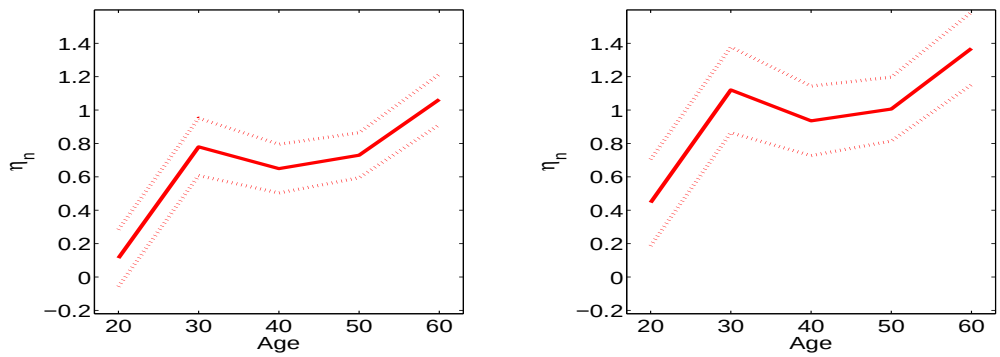
Married dummy We construct a dummy variable that is one if worker is married, as inferred from the answer to "(Are/Is)(name/you) now married, widowed, divorced, separated or never married?". We use this information to calculate the proportion of married unemployed workers in each state, period, and age group.

Unemployment over population ratio We identify a worker as unemployed if he is non-employed and he is actively searching for a job using the variable EMPSTAT in IPUMS. The relevant question to assess his/her state is the following: "By (the week before last/last week), I mean the week beginning on Sunday, (date), and ending on Saturday, (date), did (name/you) do ANY work for (pay/either pay or profit)? 1. Yes 2. No 3. Retired 4. Disabled 5. Unable to work. A worker is actively searching for a job if he answers positively to the following question: "Have you been doing anything to find work during the last 4 weeks?".

Unemployment duration Given the current employment status of the worker (see above), the unemployment duration of the current unemployment spell is calculated using the variable DURUNEMP in IPUMS which reports the number of consecutive weeks for which the unemployed worker has remained jobless. The reported number is capped at 98 weeks. For each age group, the average unemployment duration in Section 4.3 is calculated over the sample period 1990-2010

using a sample of male workers unemployed at the time of the survey, and with positive unemployment duration. The average is weighted using CPS provided weights.

Wage profile The life cycle profile of wages is used as calibration targets, see Table 4 and Figure 4. These profiles are calculated using CPS data over the period 1990 to 2010. We use a sample of male workers with 20 to 64 years of age, who are employed and have received positive labor income in the week of the interview. We regress the log of "usual labor earnings per week at the current job, before deductions" (variable EARNWEEK) deflated using the CPI index and divided by hours worked in the previous week, on a full set of yearly age dummies and on dummies for four educational groups (high school dropouts, completed high school, some college and college degree or more), marital status (equal to one if married), race (equal to one if white), being US native and for state and year. Observations are weighted using the personal weight provided by CPS. We exponentiate the estimated dummy coefficients for age to calculate relative wages by age. To construct the educational dummies we again use the variable EDUC. Hours worked in previous week are calculated using variable HRSWORK.



(a) CPS results with one lag IV

(b) CPS results with three lags IV

Notes: Estimates of β_n in (15) when benefits are instrumented with its own lagged value. Panel (a) uses one lag as IV, Panel (b) three lags. Other details are as in Figure 1.

Figure A2: Elasticity of unemployment to benefits by age, CPS results with IV

A.3 The PSID

The Panel Study of Income Dynamics (PSID) started in 1968 collecting information on a sample of roughly 5,000 households. Of these, about 3,000 were representative of the US population as a whole (the core sample), and about 2,000 were low-income families (the Census Bureau's Survey of Economic Opportunities, or SEO sample). We use the core and SEO samples in our analysis, dropping the

Latino and Immigrant samples. Our sample focuses on male individuals with 21 to 65 years of age who at least at some point over the sample period 1978-1992 were heads of household.

Age To minimize measurement error we construct the variable age by using information on year of birth from the individual files and define age as the difference between the survey year and year of birth. For those heads with no information on year of birth, we utilize the first record on self-reported age available in the survey and then construct a consistent age series.

Education Up to 1991 (1990 data) the relevant question was coded according to: 1 if 0-5 grades completed, 2 for 6-8 grades, 3 for 9-11 finished grades, 4 for 12 grades (high school), 5 for 12 grades plus non-academic training, 6 for college dropout, 7 for college degree with no advanced degree, 8 for college and advanced degree and 9 to not available. Starting from 1992, the education variable corresponds to actual grade of school completed with figures in the 0-16 range. The education variable is recoded so as to belong to one of three following categories: high school graduate, college dropout, and bachelor degree or college and advanced/professional degree.

Employment (unemployment) status dummies The employment status is inferred using the question "Are you (head) working now, looking for work, retired, keeping house, a student or what?". The household head is unemployed if at the interview date he is without a job and is actively looking for work.

Family size and *Number of kids* They are constructed using answers to: "Is someone other than this year's head/wife included in the family unit? [Which is his/her] relationship to head?".

Food consumption Food consumption is reported directly from PSID. Food consumption is the average weekly expenditures on food at home per capita in the household. Since interviews are usually conducted around March, it has been argued that people report their food expenditure for an average week around that period, rather than for the previous calendar year as is the case for family income. For robustness exercises we used both food consumption at home and out of home which is constructed using answers to the questions: "Did you (or anyone in your family) receive government food-stamps last month? In addition to what you bought with foodstamps, did you (or anyone in your family) spend any money on food that you use at home? How much? Do you have any food delivered to your door which is not included in that? About how much do you (or anyone else in your family) spend eating out, not counting meals at work or at school?". We drop food consumption data that belong to either the bottom or the top percentile of the distribution of food expenditures per capita in the household.

Total consumption expenditures in non durables goods This is the imputation by

Hryshko, Luengo-Prado and Sorensen (2010) for total consumption expenditures in non durable goods using CEX data, which extend the sample selection criteria by Blundell, Pistaferri and Preston (2008).[31] Relative to Blundell, Pistaferri and Preston (2008), the imputation by Hryshko, Luengo-Prado and Sorensen (2010) uses data on regional price indexes rather than US city averages, disregards information on prices of transportation and alcohol, it drops the numbers of kids as independent regressor, it adds dummy variables to account for marital status. The table below reproduced from Hryshko, Luengo-Prado and Sorensen (2010) reports the variables and the coefficients used in their imputation. The definition of nondurable consumption is the same as in Attanasio and Weber (1995): it is the sum of food (defined above), alcohol, tobacco, and expenditure on other nondurable goods, such as services, heating fuel, public and private transport (including gasoline), personal care, and semidurables, defined as clothing and footwear. This definition excludes expenditure on various durables, housing (furniture, appliances, etc.), health, and education. It corresponds to the average weekly expenditures at home per capita in the household. We drop data on total consumption expenditures in non durables when the imputation is based on food consumption data that belong to either the bottom or the top percentile of the distribution of food expenditures per capita in the household.

Race It is the recoding of the answer to "And, are you white, black, American Indian, Aleut, Eskimo, Asian, Pacific Islander, or another race?" so as to get three groups: white, black and other.

Region This variable can take four values corresponding to the four regions Northeast, Midwest, South and West where the household head resides.

Wages They are constructed using information on labor income and yearly hours. Labor income corresponds to total annual labor income from all jobs. Self-employed income is split between labor and capital income. In this case only the labor part is added. Yearly hours correspond to total annual hours worked for money, from family files. It refers to all possible jobs of the worker. Hourly wage are then obtained by dividing labor income by yearly hours. Observations where the resulting hourly wage falls below half of the minimum wage in the corresponding year are dropped. Wages are expressed in 1982-84 dollars by using the CPI price index.

Time dummies These are dummies for the year of the survey.

[31] Hryshko, Luengo-Prado and Sorensen (2010) also expand the sample period to 2002, but our sample is 1978-1992 as in Blundell, Pistaferri and Preston (2008).

Table A2: IV Regression of Food on Nondurable Expenditures, CEX: 1980-2002

Log nondurable cons.	0.730***	Log nondurable cons. x HS	0.023
	(15.84)		(1.03)
Log nondurable cons. x 1980	0.122***	Log nondurable cons. x coll.	0.089***
	(9.45)		(3.72)
Log nondurable cons. x 1981	0.103***	Log regional food CPI	0.643***
	(9.09)		(3.88)
Log nondurable cons. x 1982	0.094***	Log regional fuel-util. CPI	-0.113***
	(8.87)		(-2.75)
Log nondurable cons. x 1983	0.089***	White	0.047***
	(8.78)		(6.91)
Log nondurable cons. x 1984	0.083***	Family size	0.055***
	(8.77)		(17.34)
Log nondurable cons. x 1985	0.081***	High school	-0.252
	(8.97)		(-1.22)
Log nondurable cons. x 1986	0.076***	College	-0.924***
	(8.95)		(-4.10)
Log nondurable cons. x 1987	0.070***	Male head	0.082***
	(9.03)		(15.41)
Log nondurable cons. x 1988	0.067***	Married	-0.030**
	(9.55)		(-2.42)
Log nondurable cons. x 1989	0.061***	Age	0.012***
	(10.07)		(4.49)
Log nondurable cons. x 1990	0.051***	Age sq./100	-0.011***
	(10.05)		(-4.13)
Log nondurable cons. x 1991	0.043***	Born 1924-1932	-0.017*
	(9.51)		(-1.67)
Log nondurable cons. x 1992	0.041***	Born 1933-1941	-0.012
	(9.56)		(-0.90)
Log nondurable cons. x 1993	0.038***	Born 1942-1950	-0.004
	(9.52)		(-0.24)
Log nondurable cons. x 1994	0.034***	Born 1951-1959	0.001
	(9.64)		(0.06)
Log nondurable cons. x 1995	0.030***	Born 1960-1968	0.019
	(9.51)		(0.80)
Log nondurable cons. x 1996	0.023***	Born 1969-1978	0.029
	(8.92)		(1.02)
Log nondurable cons. x 1997	0.020***	Northeast	-0.013**
	(9.47)		(-2.33)
Log nondurable cons. x 1998	0.017***	Midwest	-0.061***
	(9.64)		(-11.48)
Log nondurable cons. x 1999	0.013***	South	-0.037***
	(8.57)		(-7.06)
Log nondurable cons. x 2000	0.011***	Constant	0.085
	(9.59)		(0.24)
Log nondurable cons. x 2001	0.006***	Adj. R sq.	0.721
	(7.58)		
N	40,630	F	1264.1

Notes: t-statistics in parentheses. Instruments for log nondurable consumption (and its interaction with year and education dummies) are the averages of log head's wages specific to cohort, education, and head's sex in a given year (and their interactions with year and education dummies). *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

A.4 Mathematica data

Mathematica conducted two surveys on behalf of the Department of Labor: (i) the Pennsylvania Reemployment Bonus Demonstration, a sample of 5,678 job losers in Pennsylvania in 1991; (ii) the Study of Unemployment Insurance Exhaustees, a sample of 3,907 workers covered by UI benefits in 1998 in 25 states of the US. The datasets are publicly available through the Upjohn Institute. The information in the two datasets is similar. They contain information on prior wages, weeks of UI paid, as well as demographic characteristics, household income, job characteristics (tenure, occupation, industry), and receipt of severance pay. Since Pennsylvania is not included in the Exhaustees study, there is only one year of data for each state in the sample. We use the sub-sample of the two data sets provided by Chetty (2008), who focuses on prime-age unemployed male workers and make exclusions analogous to those applied to SIPP. In particular all observations with missing data on severance payments, years of job tenure, reported survey durations, or variables used to predict net liquid wealth are excluded. We also exclude temporary layoffs (individuals who expected a recall). The final sample comprises 2441 spells, 18% of them for workers who have received some severance payment. Below we describe more in details the variables used in the analysis:

Unemployment duration The unemployment duration is computed as the difference in weeks between the date when worker finds the job and the date when the worker lost his job, as inferred from the answers to the following questions: "What was the last date that you worked on that job before you applied for unemployment insurance benefits on (claims date)?".

Severance pay This is a dichotomic variable that equals one if the worker has received a severance pay from the employer at the time of job displacement, according to the answer to the question "When that job ended, did you receive severance pay, a buyout or some other payment?".

Tenure spline This is spline in the number of years spent working at the firm where the worker was laid off, as inferred from the answers to "Now, I'd like to ask you about the job you had just before you filed for unemployment benefits: When did you first start working for that employer?"; and "what was the last date that you worked on that job before you applied for unemployment insurance benefits?".

Wage spline A spline of log wages in the pre-unemployment job. Wages are calculated using the question "How much did you usually make, before taxes and other deductions, per week when that job ended? Please include tips, commissions, and regular overtime".

Unemployment benefits The log of the weekly UI benefit as reported in the Math-

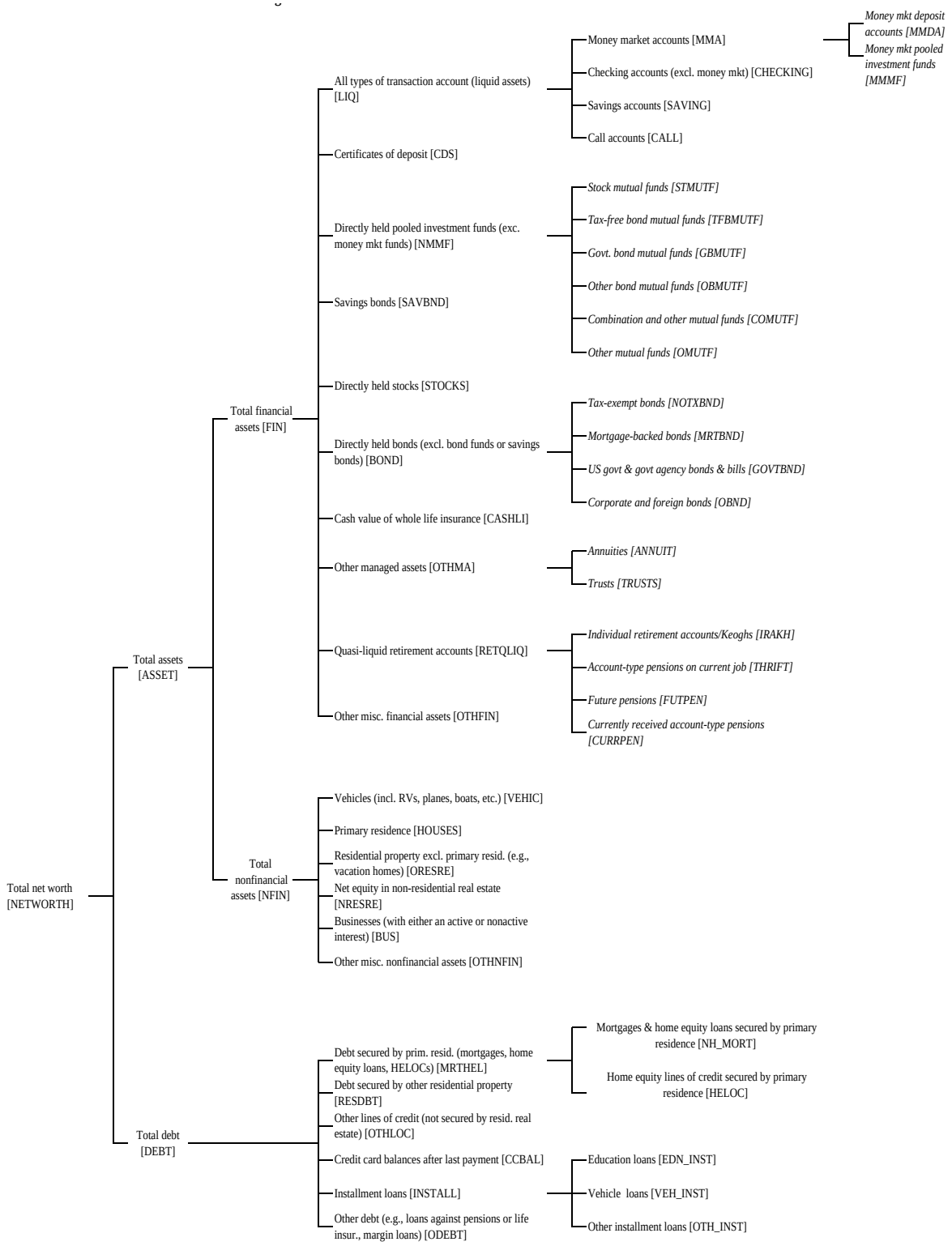
ematica data. This information comes directly from the administrative data.

Educational dummies A series of dichotomic variables for dropout and college graduate workers, as inferred from the answer to the question "What is the highest diploma or degree you have received?".

A.5 SCF

The Survey of Consumer Finances is a triennial statistical survey of the balance sheet, pension, income and other demographic characteristics of families in the United States. Data are collected by the National Opinion Research Center at the University of Chicago under the sponsorship of the Federal Reserve Board. The SCF is intended to provide accurate descriptions of the current financial situations of US households, the data are primarily cross-section in nature, although some panel data have also been collected in recent years. Here we use the 2007 cross-section available at http://www.federalreserve.gov/econresdata/scf/. Since a large share of wealth is held by a relatively small share of the population, the SCF uses a dual sample frame, with a standard representative sample supplemented by a special sample of high-income taxpayers (see below). To calculate statistics we use use sample weights as provided by SCF and we include all implicates. Our sample consists of household heads of 20 to 65 years of age who have been employed at least at some point of their life. The survey collects very detailed information on assets and liabilities, and the composition of household wealth which we use to construct the variable *Household's net worth* following the criteria detailed in Figure A3.

Household's average quarterly income in previous calendar year. It includes wages, self-employment and business income, taxable and tax-exempt interest, dividends, realized capital gains, food stamps and other support programs provided by the government, pension income and withdrawals from retirement accounts, Social Security income, alimony and other support payments, and miscellaneous sources of income." In calculating averages we drop households whose income is greater than 5 millions, which represents less than 1% of the households in the survey. The resulting average is divided by four to obtain a measure of households' quarterly income.



Notes: Names in brackets refer to variables in the SCF Bulletin extract data.

Figure A3: Calculation of Net Worth in SCF

B Derivation of $\tilde{\varrho}_n$ in the model of Section 2

In this Appendix we extend the model of Section 2 in three dimensions:

1. We allow for the possibility that young workers in period one could save.

2. We assume that the benefit levels set by the government can affect the present value of the tax revenue available for the UI programm. This is a natural equilibrium outcome when, as in the quantitative analysis, the UI program is financed through labor income taxes since benefits affect tax revenue through their effects on employment as well as on workers' human capital (which is accumulated on the job and/or lost upon unemployment). As a result the government budget constraint is as follows:

$$T\left(b_y, b_o\right) \geq \beta_y \mu_y b_y + \beta_o \mu_o b_o. \tag{27}$$

3. We recognize that the optimal choice of benefits might be subject to some feasibility constraints, that impose that benefits can not fall below a minimum level $\bar{b}_n$ so that the constraint in (10) has to be satisfied. In the quantitative analysis of Section 4 this minimum level is set to zero, so that $\bar{b}_n = 0$.

B.1 Notation

Since young workers can save, outcomes when young affect workers decisions when old. Generally worker's choices are now contingent on the entire worker's history at the time when choices are made. In particular, this means that workers choose assets in periods $i = 2, 3, 4$ contingent on whether in period 2 the worker was unemployed , $j =$ u, or employed, $j =$ e. Similarly assets decisions in period $i = 5, 6$ are contingent on workers employment state, $j =$ u,e in period 2 as well on worker's employment state $z =$ u,e in period 5. Let a_i^j denote asset level in period $i = 3, 4, 5$, which is chosen in period $i - 1$ conditional on period two employment state $j =$ u,e. Similarly let a_i^{jz} denote asset level in period $i = 6$, which is chosen in period five, conditional on period two employment state $j =$ u,e and period five employment state $z =$ u,e. Clearly since all workers are initially identical, assets levels in period two, a_2, are the same for all workers. We can then denote by $\mathbf{a_i}$, $i = 3, 4, 5, 6$ the vector of history dependent choice at $i - 1$ for next period asset values, so that $\mathrm{a_i} = (a_i^u, a_i^e), \forall i = 3, 4, 5, \quad while \quad \mathbf{a_6} = (a_6^{uu}, a_6^{ue}, a_6^{eu}, a_6^{ee})$With a slight abuse of notation we can also collect into a single vector all choices for next period assets $\mathbf{a} = (a_2, \mathbf{a}_3, \mathbf{a}_4, \mathbf{a}_5, \mathbf{a}_6)$. By applying the same logic to the choices for the unemployment probabilities in period two and five, we have that all workers choose the same unemployment probability μ_y in period two, while the choice

for the unemployment probability in period five is μ_o^j, which is contingent on employment state in period 2, j =u,e. We can then define by $\mu = (\mu_y, \mu_o^u, \mu_o^e)$the vector of choices of within-period unemployment probabilities. Let $p^j(\mu_y)$ denote the probability of being in state j = u,e in period 2 and by $p^{jz}(\mu)$, the probability of being in state j = u,e in period 2 and in state z = u,e in period 5. Clearly we have $p^u(\mu_y) = \mu_y$ and $p^e(\mu_y) = 1 - \mu_y$, which allow to express $p^{jz}(\mu)$ as equal to $\mathrm{p}^{jz}(\mu) = p^j(\mu_y)p^z(\mu_o^j)$.This makes explicit that the choice for the unemployment probability in period 5 is conditioned on the employment state in period two.

Since wage income is deterministic in age, consumption when employed in any period $i = 1, 2, 3, 4, 5, 6$ can be expressed as function of current period assets and next period assets so that $\mathrm{c}_i^e(a_i, a_{i+1}) = w_i + \frac{a_i}{\beta} - a_{i+1}$where $w_4 = w_5 = w_6 = \overline{w}$. In period 2 and 5, the worker could be unemployed and his consumption is given by $\mathrm{c}_2^u(a_2, a_3) = b_y + \frac{a_2}{\beta} - a_3, \quad and \quad c_5^u(a_5, a_6) = b_o + \frac{a_5}{\beta} - a_6$,respectively.

B.2 Worker's problem

The utility at birth of workers is equal to the sum of the discounted utilities obtained by the worker in the first two periods of his life V^f, $i = 1, 2$, in the second two periods V^s, $i = 3, 4$, and the last two periods $V^l, i = 5, 6$, which are given by

$$
\begin{aligned}
V^f(\mu_y, a_2, \mathbf{a_3}) &= u(w_1 - a_2) + \beta \left[\psi(\mu_y) + \sum_{j=u,e} p^j(\mu_y) u(c_2^j(a_2^j, a_3^j)) \right], \\
V^s(\mu_y, \mathbf{a_3}, \mathbf{a_4}, \mathbf{a_5}) &= \beta^2 \sum_{j=u,e} p^j(\mu_y) \left[u(c_3^e(a_3^j, a_4^j)) + \beta u(c_4^e(a_4^j, a_5^j)) \right] \\
V^l(\mu, \mathbf{a_5}, \mathbf{a_6}) &= \beta^4 \sum_{j=u,e} \sum_{z=u,e} p^{jz}(\mu) \left[\psi(\mu_o^j) + u(c_5^z(a_5^j, a_6^{jz})) + \beta u(c_6^e(a_6^{jz})) \right]
\end{aligned}
$$

The utility at birth of workers can then be expressed as equal to

$$
U(b_y, b_0) = \max_{\mu, \mathbf{a} \geq 0,} \left\{ V^f(\mu_y, a_2, \mathbf{a_3}) + V^s(\mu_y, \mathbf{a_3}, \mathbf{a_4}, \mathbf{a_5}) + V^l(\mu, \mathbf{a_5}, \mathbf{a_6}) \right\} \tag{28}
$$

which fully characterizes the worker's problem.

B.3 Government's problem

The government chooses b_y and b_o to maximize worker's utility at birth in (28). In solving the problem the government takes into account that worker's unemployment probabilities are given by $\mu = \arg\max \left\{ \max_{\mathbf{a} \geq 0} \left[V^f(\mu_y, a_2, \mathbf{a_3}) + V^s(\mu_y, \mathbf{a_3}, \mathbf{a_3}, \mathbf{a_5}) + V^l(\mu, \mathbf{a_5}, \right. \right.$ defines μ as a function of b_y and b_o, so we have $\mu_y = \mu_y(b_y, b_0)$, $\mu_o^u = \mu_o^u(b_y, b_0)$, and $\mu_o^e = \mu_o^e(b_y, b_0)$, which allow to define the unemployment level in period five as equal to $\mu_o(b_y, b_0) = \mu_y(b_y, b_0)\mu_o^u(b_y, b_0) + [1 - \mu_y(b_y, b_0)]\, \mu_o^e(b_y, b_0)$.The Lagrangian

of the government problem can then be written as

$$L(b_y, b_o, \lambda, \omega_y, \omega_o) = U(b_y, b_o) + \lambda \left[T\left(b_y, b_o\right) - \beta_y \mu_y(b_y, b_o) b_y - \beta_o \mu_o(b_y, b_0) b_o\right] \quad (29)$$

$$+\beta_y \omega_y \left(b_y - \bar{b}_y\right) + \beta_o \omega_o \left(b_o - \bar{b}_0\right) \quad (30)$$

which incorporates both the government budget constraint in (27) and the positive benefits constraint in (10). The constraint imposed by workers' choices for search effort are embodied in the construction of the functions $\mu_y(b_y, b_0)$, $\mu_o^u(b_y, b_0)$, and $\mu_o^e(b_y, b_0)$. After using the general envelope theorem, we obtain that it is optimal to increase b_n if

$$\beta_n \mu_n E\left[u'\left(c_{un}\right)\right] + \beta_n \omega_n > \lambda \beta_n \mu_n + \lambda \sum_{i=y,o} \beta_i \frac{\partial \mu_i}{\partial b_n} b_i - \lambda \frac{\partial T}{\partial b_n} \quad (31)$$

where $E\left[u'\left(c_{un}\right)\right]$ denotes the expected marginal utility of consumption of an unemployed worker of age $n = y, o$ (period 2 or 5) which for $n = y$ is simply equal to $\mathrm{E}[u'\left(c_{uy}\right)] = u'\left(c_2^u(a_2, a_3^u)\right)$since all unemployed young workers share the same history and consume the same. But for $n = o$, the expected marginal utility of consumption of an unemployed worker is equal to $\mathrm{E}[u'\left(c_{uo}\right)] = \frac{\mu_o^u u'\left(c_5^u(a_5^u, a_6^{uu})\right) + \mu_o^e u'\left(c_5^u(a_5^e, a_6^{eu})\right)}{\mu_y \mu_o^u + (1-\mu_y)\mu_o^e}$.which recognizes that the consumption level of unemployed old workers depends on their employment status in period two, which could affect their asset position in period five. In the expression (31) the second term in the left hand side and the last two terms in the right hand side of the inequality are novel relative to the first order condition (7) obtained in the simplified version of the model. By rearranging, we obtain that (31) is equivalent to

$$\widetilde{\varrho}_n \equiv \frac{E\left[u'\left(c_{un}\right)\right] + \frac{\omega_n}{\mu_n}}{1 + \widetilde{\eta}_n - \frac{\partial T}{\partial b_n} \cdot \frac{1}{\beta_n \mu_n}} > \lambda \quad (32)$$

where

$$\widetilde{\eta}_n \equiv \sum_{i=y,o} \frac{\partial \mu_i}{\partial b_n} \cdot \frac{\beta_i b_i}{\beta_n \mu_n} \quad (33)$$

is the modified elasticity of age-group j unemployment to benefits as in (12). Equation (32) corresponds to the expression for $\widetilde{\varrho}_n$ in (11). Generally there are welfare gains from increasing transfers to young unemployed workers at the expense of the old whenever

$$\widetilde{\varrho}_y > \widetilde{\varrho}_o. \quad (34)$$

This is the logic behind our modified redistribution formula $\widetilde{\varrho}$.

B.4 Back to the simple formula

Notice that when $a_2 = \mathbf{a_3} = \mathbf{a_4} = 0$, we also have that $a_5^u = a_5^e$ and $a_6^{uz} = a_6^{ez}$ $\forall z =$u, e which means that assets choices are independent of the employment state

of workers in period two. In this case the employment choices of old workers become independent on the past history of workers $\mu_o^u = \mu_o^e$, and the cross elasticity in (33) coincides with the simple elasticity studied in the main text. The simple formula of the main text is obtained when we also have $\omega_n = 0$, $\forall n = y, 0$ and the tax revenue allocated to the UI programm is independent of the UI benefits set by the government, so that $\frac{\partial T}{\partial b_n} = 0 \ \forall n = y, o$.

C Computational details

Here we discuss first how we solve the quantitative model of Section 4. Then we discuss how we calculate derivatives and redistribution formulas. Finally we turn to computational details about solving the optimal unemployment insurance programm when search effort is observable.

C.1 Solving the baseline economy

We discretize the state space of value functions. For points within the grid we interpolate using quadratic methods. The value functions for different n are constructed by backward induction, starting from $n = \bar{n}_w$ and then back until $n = 1$. In solving the model we impose (24) by using a recursive formulation. Let $\mathrm{C}^r = \frac{1-\beta^{\bar{n}_r}}{1-\beta}\pi$,denote the present value of the cost to the government of providing retirement pensions to a worker who has just retired. Let $C^e(n, e, a)$ denote the cost to the government of providing the transfers net of taxes dictated by the government policy to an employed worker of age n, human capital e and with assets a. Similarly let $C^u(n, e, a)$ and $C^*(n, e, a)$ denote the analogous cost to the government when providing transfers to an unemployed worker with no human capital loss, and to an unemployed worker who, at some time during the unemployment spell, has experienced a loss in human capital, respectively. In calculating these cost functions the choice of workers for next period assets a' and the unemployment probability μ are taken as given. This is why all the state variables of the worker's problem enter the definition of the government cost function. Let $a^e(n, e, a)$, $a^u(n, e, a)$ and $a^*(n, e, a)$ denote the level of next period assets chosen, as function of age n, human capital e and current assets a, by a worker who is currently employed, unemployed with no loss of human capital and unemployed with human capital loss, respectively. Similarly let $\mu^u(n, e, a)$ and $\mu^*(n, e, a)$ denote the within-period unemployment probability chosen, as a function of state variables, by a worker who is unemployed with no loss of human capital and unemployed with human capital loss, respectively. Notice that for unemployed workers e refers to worker's human capital at displacement. These policy functions allow us to define explicitly the form of the government cost functions. The cost to the government of providing the transfers net of taxes dictated by the government policy to an employed worker of age n, human capital e and with assets a satisfies

$$\begin{aligned} C^e(n, e, a) &= -\tau_n w(e) + \beta(1-\delta_n) C^e(n+1, e+1, a^e(n, e, a)) \\ &\quad + \beta\delta_n \mu^u(n+1, e+1, a^e(n, e, a)) C^u(n+1, e+1, a^e(n, e, a)) \\ &\quad + \beta\delta_n [1 - \mu^u(n+1, e+1, a^e(n, e, a))] C^e(n+1, e+1, a^e(n, e, a)) \end{aligned}$$

The analogous cost when providing transfers to an unemployed worker collecting UI benefits with no human capital loss satisfies

$$\begin{aligned} C^u(n,e,a) &= \rho_n w(e) + \beta(1-\gamma)\mu^u(n+1,e,a^u(n,e,a))\,C^u(n+1,e,a^u(n,e,a)) \\ &\quad +\beta(1-\gamma)\left[1-\mu^u(n+1,e,a^u(n,e,a))\right]C^e(n+1,e,a^u(n,e,a)) \\ &\quad +\beta\gamma\mu^*(n+1,e,a^u(n,e,a))\,C^*(n+1,e,a^u(n,e,a)) \\ &\quad +\beta\gamma\left[1-\mu^*(n+1,e,a^u(n,e,a))\right]C^e(n+1,\kappa(n+1,e),a^u(n,e,a)) \end{aligned}$$

Finally the cost of the transfers to an unemployed worker collecting UI benefits who, at some time during the unemployment spell, has experienced a loss in human capital is equal to

$$\begin{aligned} C^*(n,e,a) &= \rho_n w(e) + \beta\mu^*(n+1,e,a^*(n,e,a))\,C^*(n+1,e,a^*(n,e,a)) \\ &\quad +\beta\left[1-\mu^*(n+1,e,a^*(n,e,a))\right]C^e(n+1,\kappa(n+1,e),a^*(n,e,a)) \end{aligned}$$

where these expressions are defined for $n \leq \bar{n}_w$ with the convention that $\mathrm{C}^e(\bar{n}_w + 1, e, a) = C^u(\bar{n}_w + 1, e, a) = C^*(\bar{n}_w + 1, e, a) = C^r$At birth, $n = 1$, workers have to search for a job, they have no experience and no assets so imposing (24) is equivalent to imposing the requirement that $\mathrm{C}^u(1, 0, 0) = 0$.

C.2 Calibration of the functions $\psi(\mu)$

The second derivative of the function ψ has to be negative $\psi'' \leq 0$ and it plays a key role in determining the value of the elasticity of unemployment with respect to benefits. So we decided to model its profile directly and to impose explicitly the constraint that the second derivative is always negative, $\psi'' \leq 0$. To achieve this the function $\psi(\mu)$ is parameterized in terms of six values. The value of the second derivative of ψ at $\mu = 0$, the analogous value at $\mu = 1$ and its maximum value (minimum absolute value) which is reached at an endogenously determined μ^*. All these values are constrained to be negative. In addition, the function $\psi(\mu)$ is characterized by its value at $\mu = 1$ and the the value of its first derivative at $\mu = 1$. To sum-up the function ψ is fully characterized by the following six values: $\psi(1)$, $\psi'(1) \geq 0$, $\psi''(1) \leq 0$, $\psi''(0) \leq 0$, $\psi''(\mu^*) \leq 0$ and finally by the value for μ^* at which ψ'' reaches its maximum. The profile of the second derivatives of ψ'' is a linear spline through the knots at $\psi''(1) \leq 0$, $\psi''(0) \leq 0$, and $\psi''(\mu^*) \leq 0$. We impose the constraint that ψ'' can never be greater than $\psi''(\mu^*)$. By integrating the profile of second derivatives and given an initial condition for the first derivative—which is provided by the value of $\psi'(1) \geq 0$—we obtain a characterization of the entire profile of ψ'. Given the profile of ψ' and an initial condition for ψ at $\mu = 1$, we finally obtain the entire profile of the function ψ, which is plotted in the main text. It is easy to check that the resulting ψ function is perfectly approximated

by a cubic spline evaluated at five different values where the intermediate knot μ^* is endogenously determined.

C.3 Variables definition

We discuss the construction of some variables in the model.

Mass of workers collecting UI benefits As discussed in the text, the fraction of workers of age n who are collecting UI benefits is equal to

$$\mu_n = \int_{R^+} \chi^u (n, de) \tag{35}$$

Mass of workers searching for a job Let $\chi^s (n, e)$ denote the measure of workers of age n who are searching for a job and who were displaced with human capital e. Given $\chi^e (n, e)$ and $\chi^u(n, e)$ we have that $\chi^s(n, e) = \chi^u(n-1, e) + \delta_{n-1}\chi^e (n-1, e-1)$ The right had side is the sum of two terms that measure the two inflows into the pool of searchers of age n. The first term measures the mass of workers of age $n-1$ who have collected benefits in a period and who will search for a job in the next period when they are one year older. The second term takes into account that the pool of workers searching for a job is also augmented by the fraction δ_{n-1} of the workers of age $n-1$ and human capital $e-1$ who are currently employed and lose their job. These workers will have to search for a new job in the next period when they have age n and human capital e. The mass of workers of age n searching for a job can then be defined as equal to $\sigma_n = \int_{R^+} \chi^s (n, de)$. whose interpretation is analogous to that in (35).

Job finding rate The job finding rate of workers of age n is denoted by f_n and it is simply equal to the ratio between the mass of workers of age n who find a job in a period and the pool of searchers of age n in that period:

$$f_n = \frac{\sigma_n - \mu_n}{\sigma_n}. \tag{36}$$

Unemployment rate In standard surveys workers are classified as unemployed if, at the interview date, workers are without a job and they are actively searching for a job. In terms of our model, this number is different depending on whether the interview were to be performed at the beginning of, during or at the end of the model period, which corresponds to one quarter in our calibration. To account for this problem we assume that the unemployment rate of workers of age n is equal to $u_n = 0.5\sigma_n + 0.5\mu_n$. This expression can be justified by assuming that workers interviews occur randomly over the period and that workers find jobs at a constant uniform linear probability in the period. Let f_n denote the model probability of

finding a job in a period for a given age group n. Assume that the probability of finding a job in the first ith fraction of the period is if_n where $i \in [0,1]$.[32] Then the probability that a worker of age n is classified as unemployed in the period is equal to 1-$\int_0^1 if_n di = 1 - 0.5f_n$ Given these considerations we can then define the unemployment of workers of age n as equal to $\mathrm{u}_n = (1 - 0.5f_n)\,\sigma_n = 0.5\sigma_n + 0.5\mu_n$ where the last equality uses the definition of the age specific job finding rate in (36).

Unemployment duration One period in the model corresponds to one quarter. Unemployment duration in the CPS data is measured in weeks. To convert the unemployment duration of the model into weeks we proceed as follows. Let f_n denote the probability of finding a job in a period for a given age group n. Remember that one period in the model correspond to one quarter. Now assume that the quarter is divided into 13 weeks and that workers are randomly interviewed in any of these 13 weeks to infer the duration of their current unemployment spell. Also assume that the probability that a worker finds a job in any week of the quarter is

$$\bar{f}_n = 1 - (1 - f_n)^{\frac{1}{13}}$$

This guarantees that the probability of remaining unemployed in all the 13 consecutive weeks of the quarter is $\left(1 - \bar{f}_n\right)^{13} = 1 - f_n$. Then, if workers have an unemployment duration in the model equal to $j = 0, 1, 2, 3..$, their unemployment duration in weeks is calculated as equal to $I + 13j$ where I=$\sum_{i=1}^{12} i \left(1 - \bar{f}_n\right)^i \frac{}{\sum_{i=0}^{12}\left(1-\bar{f}_n\right)^i}$, which measures the average duration in weeks of workers who have been just displaced from their previous job and start searching for a new one in the current model period. After remembering that $\sum_{i=0}^{T}\left(1 - \bar{f}_n\right)^i = \frac{1-\left(1-\bar{f}_n\right)^{T+1}}{\bar{f}_n}$ and that $\sum_{i=1}^{T} i\left(1 - \bar{f}_n\right)^{i-1} = \frac{1-\left(1+\bar{f}_n T\right)\left(1-\bar{f}_n\right)^T}{\left(\bar{f}_n\right)^2}$ we can express I as equal to

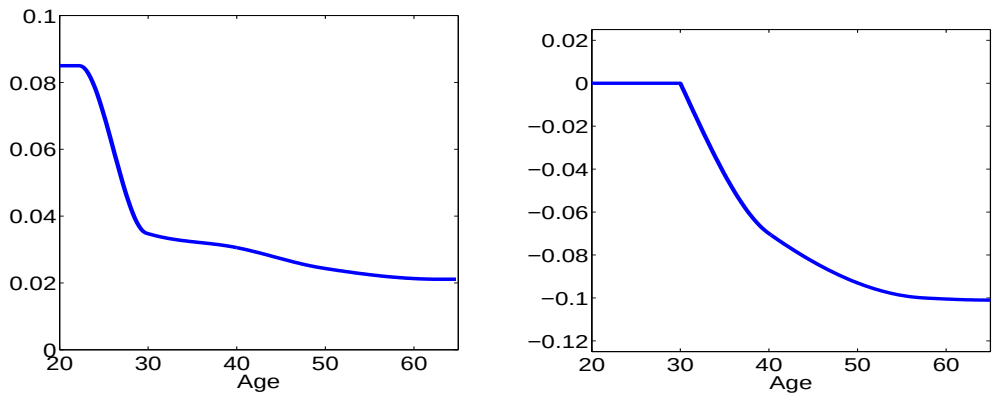
$$I = \frac{\left(1 - \bar{f}_n\right) - \left(1 + 12 \times \bar{f}_n\right)\left(1 - \bar{f}_n\right)^{13}}{\bar{f}_n - \bar{f}_n\left(1 - \bar{f}_n\right)^{13}}$$

This is the expression for I used in the computer code.

C.4 Age profiles of separation rates and wage losses upon re-employment in baseline calibration

Figure A4 plots the age profiles in the baseline calibration of separation rates, δ_n, panel (a) and wage losses upon re-employment $\overline{\kappa}_n - 1$, panel (b).

[32]Notice that the probability if_n can also be justified by taking a Taylor expansion, around $f_n = 0$, of the expression for the geometric probability of finding a job before i, which is equal to $1 - (1 - f_n)^i$.



(a) Separation rates, δ_n

(b) Wage losses upon reemployment, $\overline{\kappa}_n - 1$

Figure A4: Some functions in the baseline calibration of laboratory economy

C.5 Calculating elasticities and redistribution formulas in the quantitative analysis

Let $\rho = \{\rho_1, ..., \rho_{\overline{n}_w}\}$ denote the vector containing the entire age profile of UI replacement rates in a baseline economy. To calculate elasticities and redistribution formulas at age n of the corresponding baseline economy, we consider changes in replacement rates at p consecutive quarters starting from age n. For every n we then consider two economies one with lower and one with higher replacement rates at age n, $\rho_n^i = \{\rho_1, ..., \rho_{n-1}, \vartheta_n^i, \vartheta_{n+1}^i, ..., \vartheta_{n+p-1}^i, \rho_{n+p}, .., \rho_{\overline{n}_w}\}$, $i = l, h$ where $\vartheta_{n+j}^l = \rho_{n+j} - \frac{\epsilon}{2}$ and $\vartheta_{n+j}^h = \rho_{n+j} + \frac{\epsilon}{2}$, $\forall j = 0, 1, ...p-1$. In the paper we work with $\epsilon = 0.02$ and $p = 4$, which corresponds to a change in benefits for an age group of one year. We consider one year changes in benefits both to increase sample size and to reduce the likelihood that the change in policy affects workers' search effort decisions though effects on unemployment duration dependence in benefits, which is an issue somewhat unrelated to age-dependent policies. To avoid this problem we could have indexed the level of replacement rates, rather than to current age, to the age at which the worker is displaced. But this specification would require having an additional state variable in the worker problem, which would involve additional computational costs. We checked that results are little affected when choosing $p = 3$ or $p = 5$ rather than $p = 4$.

C.5.1 Calculating η_n

Given the policy change for age group n the elasticity of unemployment is calculated as equal to

$$\eta_n = \frac{\sum_{i=0}^{p-1} d\mu_{n+i}\rho_{n+i}}{\epsilon \sum_{i=0}^{p-1} \mu_{n+i}^0}, \tag{37}$$

In the expression μ^0_{n+i} denotes the measure of workers of age $n+i$ who are collecting UI benefits before the policy change while $d\mu_{n+i}$ denotes the difference between the level of workers of age $n+i$ who are collecting UI benefits in the economy with high benefits ρ^h_n and the analogous level in the economy with low benefits ρ^l_n. Notice that for completeness $d\mu_{n+i}$ should be indexed to the policy change considered. Yet to simplify notation we did not make this dependence explicit. Conceptually in the expression (37), the exogenous change in benefits is equal to $db_n = w^0_n d\rho_n = w^0_n \epsilon$, where w^0_n denotes the average wage at displacement of the workers of age n who are collecting UI benefits before the policy change. When $p = 1$, (37) reads as $\eta_n = \frac{d\mu_n \rho_n}{\epsilon \mu^0_n}$ which is simply the elasticity of unemployment with respect to replacement rates. So in calculating the unemployment elasticity, the denominator includes just the really exogenous component of the change in government expenditures for the UI programm, omitting any induced effect due to either changes in unemployment or in workers' human capital. Notice that (37) takes into account that benefits are changed for p consecutive quarters. The expression in (37) can be interpreted as a simple weighted average of the relevant unemployment elasticities with respect to UI replacement rates evaluated at n up to $n+p-1$, with weights equal to the relative unemployment of the age group, $\frac{\mu^0_{n+i}}{\sum_{i=0}^{p-1} \mu^0_{n+i}}$. Finally notice that for the purpose of calculating unemployment elasticities unemployment is defined as the mass of workers who are collecting UI benefits, which is consistent with the empirical analysis.

C.5.2 Calculating $\widetilde{\varrho}_n$

Consider the model in Section B and let $\mathrm{D}(\mathrm{b}_y, b_o) = \sum_{i=y,o} \beta_i \mu_i(b_y, b_o) b_i - T(b_y, b_o)$denote the government budget deficit, where T denotes the expected present value of the tax revenue collected by the government to finance the UI program. Notice that the denominator of the modified formula in (11) is equal to the ratio of the derivative of the government budget deficit with respect to the age specific level of benefits and the level of the group specific unemployment rate—i.e. it is equal to $\frac{\partial D}{\partial b_n} \cdot \frac{1}{\mu_n}$. When b_n marginal increases, the budget deficit increases because of i) the increase in the transfers received by the already unemployed workers targeted by the policy change (equal to μ_n), ii) the increase in transfers due to the increase in unemployment of all different age groups (which is measured by the term $\sum_{i=y,0} \frac{\partial \mu_i}{\partial b_n} \beta_i b_i$), and iii) the reduction in tax revenue (which is measured by the term $-\frac{dT}{db_j}$). This leads to an alternative expression for $\widetilde{\varrho}_n$ (11) as equal to

$$\widetilde{\varrho}_n = \frac{E\left[u'\left(c_{un}\right)\right] + \frac{\omega_n}{\mu_n}}{\frac{1}{\beta_n \mu_n} \cdot \frac{\partial D}{\partial b_n}} \tag{38}$$

This is the expression we use to calculate $\widetilde{\varrho}_n$ in the quantitative analysis of Section 4 where the government deficit is defined as equal to

$$D(\rho) = \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \rho_n w(e) \chi^u(n, de) + \sum_{n=\bar{n}_w+1}^{\bar{n}_r} \beta^n \pi \chi^r(n) - \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \tau_n w(e) \chi^e(n, de) \tag{39}$$

The feasibility constraint in the quantitative analysis is $\rho_n \geq 0$. To calculate ω_n we notice that, if the constraint in (10) is not binding for age group n, we have that $\omega_n = 0$, while, if the constraint is binding, ω_n can be calculated by measuring by how much welfare would fall if we were to increase the value of the constraint $\bar{b}_n$. If we denote by W the expected welfare of workers at birth under a given choice of ρ, we should have that $\mathrm{dW}_{\overline{d\bar{b}_n = -\beta^n \omega_n}}$ which is zero when the constraint is not binding. Notice that the present value Lagrange multiplier of the feasibility constraint is $\beta^n \omega_n$, exactly as in (30). The expected marginal utility of consumption of unemployed workers of age n is calculated as equal to the average expected marginal utility of all age groups affected by the policy change, $\frac{1}{p}\sum_{i=0}^{p-1} E\left[u'\left(c_{un+i}\right)\right]$. Overall the modified formula in the quantitative analysis is calculated as equal to

$$\widetilde{\varrho}_n = \frac{\frac{1}{p}\sum\limits_{i=0}^{p-1}\left\{E\left[u'\left(c_{un+i}\right)\right] + \frac{\omega_{n+i}}{\mu_{n+i}}\right\}}{\frac{dD}{\epsilon \sum\limits_{i=0}^{p-1} \beta^{n+i} \mu_{n+i}^0 w_{n+i}^0}}, \tag{40}$$

which, exactly as in (37), takes into account that benefits are changed for p consecutive quarters. In the expression above w_n^0 denotes again the average wage at displacement of the workers of age n who are collecting UI benefits before the policy change, while μ_n^0 is the mass of workers of age n who are collecting UI benefits before the policy change. As in (37), the exogenous change in benefits is equal to $db_n = w_n^0 d\rho_n = w_n^0 \epsilon$. The denominator of (40) corresponds to the denominator in (38) which is the derivative of government deficit with respect to changes in benefits. The term dD denotes the difference between the government deficit in the economy with high benefits levels ρ_n^h and the analogous value in the economy with low benefit levels ρ_n^l. In principle dD should have been indexed to the policy change considered. Yet to simplify notation we did not make this dependence explicit. Finally notice that in the denominator of the derivative of government deficit with respect to benefits, we focus just on the really exogenous change in government expenditures for the UI programm, omitting any induced effects due to either changes in unemployment or in workers' human capital.

C.5.3 Calculating the cross elasticity $\widetilde{\eta}_n$

Let $\mathrm{B}(\mathrm{b}_y, b_o) = \sum_{i=y,o} \beta_i \mu_i(b_y, b_o) b_i$denote the total amount of government money spent for unemployment insurance. It is easy to check that in the model in Section B

$$\frac{\partial B(b_y, b_o)}{\partial b_n} = \beta_n \mu_n \left(1 + \widetilde{\eta}_n\right) \tag{41}$$

To calculate $\widetilde{\eta}_n$ in (33) we first calculate the changes in the money spent for unemployment insurance B and then obtain the elasticity $\widetilde{\eta}_n$ by using the fact that (41) implies that

$$\widetilde{\eta}_n = \frac{1}{\beta_n \mu_n} \cdot \frac{\partial B(b_y, b_o)}{\partial b_n} - 1 \tag{42}$$

This is the expression we use to calculate $\widetilde{\eta}_n$ in the quantitative analysis of Section 4 where the total amount of government money spent for unemployment insurance is defined as equal to

$$B(\rho) = \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \rho_n w\left(e\right) \chi^u\left(n, de\right). \tag{43}$$

Given (41) and the policy changes discussed in Section C.5, we then calculate $\widetilde{\eta}_n$ as equal to

$$\widetilde{\eta}_n = \frac{dB}{\epsilon \sum\limits_{i=0}^{p-1} \beta^{n+i} \mu_{n+i}^0 w_{n+i}^0} - 1 \tag{44}$$

where dB is the difference in UI expenditures between the economy with high benefit levels ρ_n^h and the economy with low benefits ρ_n^l. Notice that for completeness dB should have been indexed to the policy change considered. Yet to simplify notation we did not make this dependence explicit. The logic of calculating the derivative as in (44) is analogous to the logic used to obtain (37) or (40).

C.6 Solving the optimal UI problem with observable search effort

Here we discuss how we solve the optimal life cycle unemployment insurance problem of Section 5 where search effort is observable, which corresponds to the first best problem. To solve for this problem we search for the value of consumption c^* that makes $\Upsilon\left(1, 0, c^*\right)$ in (26) equal to zero:

$$\frac{1 - \beta^{\bar{n}_w + \bar{n}_r}}{1 - \beta} c^* - Y\left(1, 0, c^*\right) = 0 \tag{45}$$

where the function $Y\left(n, e, c\right)$ denotes the expected present value of income generated by a worker of age n searching for a new job who had human capital e at the start of the current job search spell and who has not experienced any loss

in his human capital. Here c denotes the constant consumption flow granted to the worker in each remaining period of his life. Let $\overline{\mu}(n,e,c)$ denote the the within-period unemployment probability function under the optimal policy of an unemployed worker of age n, who had human capital e at the start of the current job search spell, who is granted consumption flow c for each remaining period of his life and who has not experienced any loss in human capital during the current job search spell. Also let $\overline{\mu}^*(n,e,c)$ denote the within-period unemployment probability function analogous to $\overline{\mu}(n,e,c)$ but for an unemployed worker who has already experienced a loss in human capital. The functions $\overline{\mu}(n,e,c)$ and $\overline{\mu}^*(n,e,c)$ are characterized below by (55) and by (56), respectively. Given these functions we can express Y recursively as equal to:

$$\begin{aligned} Y(n,e,c) &= \overline{\mu}(n,e,c)\beta\left[(1-\gamma)\,Y(n+1,e,c)+\gamma Y^*(n+1,e,c)\right] && (46)\\ &\quad +\left[1-\overline{\mu}(n,e,c)\right]Y^e(n,e,c) && (47)\end{aligned}$$

where

$$Y^e(n,e,c)=w(e)+\beta\left[(1-\delta_n)Y^e(n+1,e+1,c)+\delta_n Y(n+1,e+1,c)\right] \quad (48)$$

is the expected present value of income generated by an employed worker of age n with human capital e who is granted consumption level c for all the remaining periods of his life, while

$$Y^*(n,e,c)=\overline{\mu}^*(c,e,n)\beta Y^*(n+1,e,c)+\left[1-\overline{\mu}^*(n,e,c)\right]Y^e(n,\kappa(n,e),c) \quad (49)$$

is the expected present value of income analogous to $Y\,(n,e,c)$ but for an unemployed worker who has already experienced a loss in human capital. The expression in (49) incorporates the assumption that, after experiencing a loss in human capital, the worker is reemployed with human capital $\kappa(n,e)$ where e refers to worker's human capital at the start of the current job search spell.

Consider a worker of age n searching for a job who had human capital e at the start of the current job search spell, who is granted consumption flow c for each remaining period of his life and who has not experienced any loss in human capital during the current job search spell. Under the optimal policy, this worker generates a value measured in utils equal to

$$\begin{aligned} S(n,e,c) &= \max_{\mu\in[0,1]}\left\{\psi\left(\mu\right)+\mu\beta\left[(1-\gamma)\,S(n+1,e,c)+\gamma S^*(n+1,e,c)\right]\right. && (50)\\ &+ \left.(1-\mu)\,S^e(n,e,c)\right\} && (51)\end{aligned}$$

where

$$S^e(n,e,c)=u'\left(c\right)w(e)+\beta\left[(1-\delta_n)S^e(n+1,e+1,c)+\delta_n S(n+1,e+1,c)\right] \quad (52)$$

is the expected present value, again measured in utils, of the income produced by an employed worker of age n with human capital e who is granted consumption level c for all the remaining periods of his life. The present utility value of searching for a worker who has already experienced a loss in human capital is instead equal to

$$S^*(n,e,c) = \max_{\mu\in[0,1]} \{\psi(\mu) + \mu\beta S^*(n+1,e,c) + (1-\mu)\, S^e(n,\kappa(n,e),c)\} \tag{53}$$

which is analogous to $S(n,e,c)$ but for the case when the unemployed worker has already experienced a loss in human capital. For any n, e, and c the within-period unemployment probability functions under the optimal policy $\overline{\mu}$ and $\overline{\mu}^*$ are implicitly defined by (51) and (53), respectively. So we have

$$\overline{\mu}(n,e,c) = \arg_{\mu\in[0,1]} \max \{\psi(\mu) + \mu\beta\,[(1-\gamma)S(n+1,e,c) + \gamma S^*(n+1,e,c)] \tag{54}$$

$$+ (1-\mu)S^e(n,e,c)\} \tag{55}$$

and

$$\overline{\mu}^*(n,e,c) = \arg_{\mu\in[0,1]} \max \{\psi(\mu) + \mu\beta S^*(n+1,e,c) + (1-\mu)S^e(n,\kappa(n,e),c)\}\,. \tag{56}$$

For any given value of c, we can use (51), (52) and (53) to solve for S, S^e, and S^* backward starting from $n = \bar{n}_w$ after using the terminal conditions $S(\bar{n}_w+1,e,c) = S^e(\bar{n}_w+1,e,c) = S^*(\bar{n}_w+1,e,c) = 0$. The within-period unemployment probability functions $\overline{\mu}$ and $\overline{\mu}^*$ are then obtained by using (55) and (56), respectively. Given $\overline{\mu}$ and $\overline{\mu}^*$ and after using the terminal conditions $Y(\bar{n}_w+1,e,c) = Y^e(\bar{n}_w+1,e,c) = Y^*(\bar{n}_w+1,e,c) = 0$ we can use (47), (48) and (49) to calculate Y, Y^e, and Y^* which can be used to solve for the value of c^* that satisfies (45).

C.7 Consumption equivalent gains relative to baseline calibration

All consumption equivalent gains are calculated relative to the baseline calibration discussed in Section 4.3. Let's start defining the relevant policy rules under the baseline calibration for consumption, next period asset levels and within-period unemployment probabilities. Policy rules are always specified as a function of worker's age n, worker's human capital e and worker's current assets a. For unemployed workers e refers to human capital at the start of the current job search spell. More specifically, let $\widehat{c}^e(n,e,a)$, $\widehat{c}^u(n,e,a)$ and $\widehat{c}^*(n,e,a)$ denote the consumption level chosen in the baseline calibration by a worker who is currently employed, unemployed with no loss of human capital and unemployed with human capital loss, respectively. Also let $\widehat{a}^e(n,e,a)$, $\widehat{a}^u(n,e,a)$ and $\widehat{a}^*(n,e,a)$ denote the next period asset level chosen by a worker who is currently employed, unemployed with no loss

of human capital and unemployed with human capital loss, respectively. Finally let $\widehat{\mu}^u(n,e,a)$ and $\widehat{\mu}^*(n,e,a)$ denote the within-period unemployment probability chosen in the baseline calibration by a worker who is unemployed with no loss of human capital and unemployed with human capital loss, respectively. Now suppose that in every possible state consumption level choices are multiplied by a factor θ. We can then calculate the utility value from consumption obtained by the worker in each possible state after this multiplicative change in consumption levels. When the worker is employed at age n, with human capital e and asset level a the utility value he obtains from consumption becomes equal to

$$\begin{aligned} L^e(n,e,a,\theta) &= \theta^{1-\sigma}u\left(\widehat{c}^e(n,e,a)\right)+\beta(1-\delta_n)L(n+1,e+1,\widehat{a}^e(n,e,a),\theta) && (57)\\ &\quad +\beta\delta_n L^j(n+1,e+1,\widehat{a}^e(n,e,a),\theta) && (58)\end{aligned}$$

which uses the fact that the utility function is CARA and for simplicity we assumed that $\sigma \neq 1$. So the scaling factor in consumption θ can be taken out of the utility function as a multiplicative factor. The last term incorporates the fact that with probability δ_n a worker of age n has to search for a new job whose utility value from consumption is given by

$$L^j(n,e,a,\theta) = \widehat{\mu}^u(n,e,a)\,L^u(n,e,a,\theta)+\left[1-\widehat{\mu}^u(n,e,a)\right]L^e(n,e,a,\theta) \qquad (59)$$

where

$$\begin{aligned} L^u(n,e,a,\theta) &= \theta^{1-\sigma}u(\widehat{c}^u(n,e,a))+\beta(1-\gamma)L^j(n+1,e,\widehat{a}^u(n,e,a),\theta) && (60)\\ &\quad +\beta\gamma L^{j^*}(n+1,e,\widehat{a}^u(n,e,a),\theta) && (61)\end{aligned}$$

denotes the utility value from consumption when being unemployed without having experienced a loss in human capital. The function L^{j^*}in (61) denotes the utility value from consumption when searching for a job after having experienced a loss in human capital, which satisfies the following relation

$$L^{j^*}(n,e,a,\theta) = \widehat{\mu}^*(n,e,a)\,L^*(n,e,a,\theta)+\left[1-\widehat{\mu}^*(n,e,a)\right]L^e(n,\kappa(n,e),a,\theta). \quad (62)$$

In the expression above L^* denotes the utility value from consumption when being unemployed after a loss in human capital, which satisfies

$$L^*(n,e,a,\theta) = \theta^{1-\sigma}u(\widehat{c}^*(n,e,a))+\beta L^{j^*}(n+1,e,\widehat{a}^*(n,e,a),\theta). \qquad (63)$$

In writing (58), (61) and (63) we adopted the convention that $\mathrm{L}(\bar{n}_w+1,e,a,\theta) = L(\bar{n}_w+1,e,a,\theta) = L^*(\bar{n}_w+1,e,a,\theta) = \theta^{1-\sigma}\cdot\frac{1-\beta^{\bar{n}_r}}{1-\beta}u\left(c^r(a)\right)$The utility value from consumption at birth is equal to $L^j(1,0,0,\theta)$, which satisfies $\mathrm{L}^j(1,0,0,\theta) = \theta^{1-\sigma}L^j(1,0,0,1)$.Notice that $L^j(1,0,0,1)$ is the utility value from consumption at birth in the baseline calibration. Now consider a policy reform that yields a welfare gains relative to the welfare in the baseline calibration equal to $\Delta W \equiv \Delta J(1,0,0)$. The consumption equivalent gain change is calculated as equal to $\theta(\Delta W)-1$ where $\theta(\Delta W)$ is given by $\theta(\Delta W) = \left[\frac{\Delta W}{L^j(1,0,0,1)}+1\right]^{\frac{1}{1-\sigma}}$.

C.8 Baseline economy under the natural borrowing limit

We analyze our economy under the assumption that workers face a natural borrowing limit, equal to the present value of the income that the worker would obtain if he were to shirk in every working period until retirement. This implies that the assets of a worker of age n with human capital e should be greater than l(n,e)=-$\left[\frac{1-\beta^{\bar{n}_w-n+1}}{1-\beta}\rho w(e)+\beta^{\bar{n}_w-n+1}\frac{1-\beta^{\bar{n}_r}}{1-\beta}\pi\right]$.To understand the term in square brackets notice that if a worker of age n who has human capital e shirks forever, he obtains UI benefits $\rho w(e)$ in each of the $\bar{n}_w-n+1$ remaining periods of his working life and then he will obtain retirement pensions π that he will start receiving in $\bar{n}_w-n+1$ periods. Under this assumption the key equations of the model in Section 4 should be modified to incorporate the new borrowing limit. The value of being an employed worker of age $n\leq\bar{n}_w$ with human capital e and assets a will now be given by:

$$V(n,e,a)=\max_{a'\geq l(n+1,e+1)}u\left(c^e(e,a,a')\right)+\beta\left[(1-\delta_n)V(n+1,e+1,a')+\delta_n J(n+1,e+1,a')\right] \tag{64}$$

which takes into account that next period assets should be greater than $l(n+1,e+1)$. Remember that $c^e(e,a,a')=(1-\tau_n)w(e)+(1+r)a-a'$. The value of searching is again given by J(n,e,a)=max$_{\mu\in[0,1]}\psi(\mu)+\mu U(n,e,a)+(1-\mu)V(n,e,a)$The value of remaining unemployed at the end of the period should now satisfy

$$U(n,e,a)=\max_{a'\geq l(n+1,e)}u(c^u(e,a,a'))+\beta\left(1-\gamma\right)J(n+1,e,a')+\beta\gamma J^*(n+1,e,a') \tag{65}$$

where $c^u(e,a,a')=\rho_n w(e)+(1+r)\,a-a'$ denotes again current period consumption when unemployed. The function J^* denotes the value of searching after experiencing a loss in human capital, which remains untouched and again given by J$^*(n,e,a)=\max_{\mu\in[0,1]}\psi(\mu)+\mu U^*(n,e,a)+(1-\mu)V(n,\kappa_n e,a)$The value of being unemployed after a loss in human capital satisfies

$$U^*(n,e,a)=\max_{a'\geq l(n+1,e)}u(c^*(e,a,a'))+\beta J^*(n+1,e,a') \tag{66}$$

where again $c^*(n,e,a,a')=\rho_n w(e)+(1+r)\,a-a'$ and the borrowing limit is as in (65). We also still adopt the convention that V$(\bar{n}_w+1,e,a)=U(\bar{n}_w+1,e,a)=U^*(\bar{n}_w+1,e,a)=\frac{1-\beta^{\bar{n}_r}}{1-\beta}u\left(c^r\left(a\right)\right)$where $c^r\left(a\right)=\pi+\frac{ra}{1-\beta^{\bar{n}_r}}$. The government budget constraint is also untouched and reads as follows

$$\sum_{n=1}^{\bar{n}_w}\beta^n\int_{R^+}\rho_n w\left(e\right)\chi^u\left(n,de\right)+\sum_{n=\bar{n}_w+1}^{\bar{n}_r}\beta^n\pi\chi^r(n)=\sum_{n=1}^{\bar{n}_w}\beta^n\int_{R^+}\tau_n w\left(e\right)\chi^e\left(n,de\right) \tag{67}$$

where integrals are conventionally defined Lebesgue integrals. Here again $\chi^e\left(n,e\right)$ denotes the measure of employed workers of age n and experience e, $\chi^u(n,e)$

denotes the measure of unemployed workers of age n who were displaced with human capital e and finally $\chi^r(n) = \int \chi^e(\bar{n}_w, de) + \int \chi^u(\bar{n}_w, de) = \chi^r$ denotes the measure of retired workers of age n, which is constant and independent of age.

D Wage and earnings losses in the literature and in the model

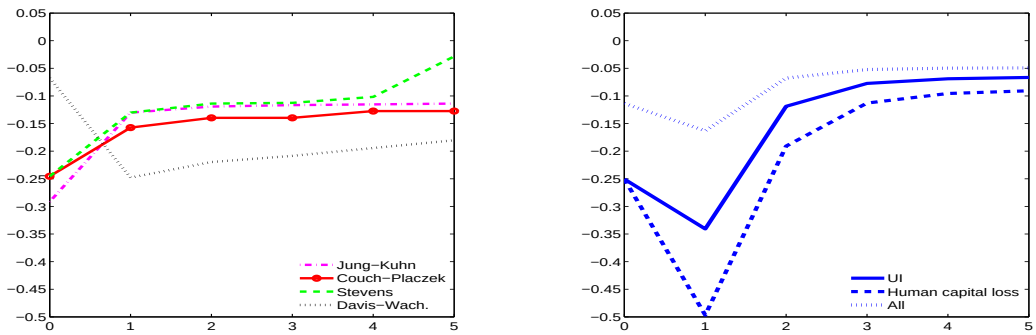
In this section we first briefly review estimates from the empirical literature on earnings losses upon displacement. We then compare estimates with measures of earnings losses in the model. We focus on two parametrizations of the model: one is the baseline calibration of Section 4.3 of the paper, the other is the re-calibrated version of the model discussed in Section 7.5 where we double the magnitude of wage losses during unemployment. We then discuss robustness to alternative characterizations of earnings losses in the model.

D.1 Earnings losses in the literature

We compare yearly earnings losses upon displacement in the model with estimates from the literature as obtained by Davis and von Wachter (2011), Stevens (1997), Couch and Placzek (2010) and also reported in Jung and Kuhn (2012). In Figure A5 we plot the profile of earnings losses at different years after worker displacement as estimated by the literature. Displacement occurs in period zero. The black dotted line corresponds to the estimates by Davis and von Wachter (2011). Davis and von Wachter (2011) focus on a sample of male employees with at least 3 years of job tenure prior to displacement and employed in firms with at least 50 employees. A worker is classified as displaced in year t if he separates from the employer in t and the employer experiences a mass layoff between $t-1$ and t roughly defined as an employment contraction of at least 30% in the period. They measure yearly labor earnings of displaced workers and compare these earnings to the earnings of workers with identical characteristics in terms of age, tenure and firm size before displacement but who did not separate from their main employers in year t, $t+1$, and $t+2$. Davis and von Wachter (2011) just provide measure of income losses in thousands of dollars. To obtain a measure of earnings losses in percentage terms, we infer from Table 1 of their paper that the average annual income of the control group in their sample is \$ 49,806, which allows us to obtain a measure of losses as a proportion of labor income of the control group.[33] Davis and von Wachter (2011) provide measures of earnings losses in recessions and in expansions. We focus on the measure during expansion years, which are similar to the average effects in their sample. The red solid line in Figure A5 corresponds to the profile of earnings losses after displacement estimated by Couch and Placzek

[33] To calculate the analogous annual earnings for workers of different age, we use our estimated age profile of labor income from CPS. For example this profile says that workers of 21 to 30 years of age earn around 72 % of the average earnings in the economy, which suggests setting an annual income of \$ 35,930 for the control group of displaced workers of this age. For other age groups we proceed analogously.

(2010), who mimic the analysis in Jacobson, LaLonde and Sullivan (1993), using Connecticut data over the period 1993-2004. Workers are defined as displaced, exactly as in Davis and von Wachter (2011). Earnings of displaced workers are compared to the earnings of continuously employed workers. Since earnings are at the quarterly frequency, we obtain a measure of yearly losses by cumulating losses in the year. The profile in Figure A5, is obtained using column FE of the table at page 27 of the Online Appendix of the paper. The green dashed line



(a) Earnings losses in data

(b) Earnings losses in model for different definition of displacement

Notes: Panel (a) plots the profile of yearly earnings losses in the model and in several papers in the literature. The black dotted line corresponds to the estimates by Davis and von Wachter (2011), the red solid line to those by Couch and Placzek (2010), and the green dashed line to those by Stevens (1997). The purple dash dotted line is the profile of earnings losses generated by the model of Jung and Kuhn (2012). Panel (b) shows the profile of yearly earning losses for alternative definitions of worker displacement in the model. The blue solid line corresponds to the annual earnings losses of workers who collect UI benefits. The blue dotted line corresponds to the annual earnings losses of workers who separate from their job independently of whether they collect UI benefits in a period. The blue dashed line is the profile of earning losses for all workers who in the model lose their job and experience some loss in their human capital during their first unemployment spell.

Figure A5: Profile of yearly earnings losses after displacement

in Figure A5 corresponds to the profile of earnings losses estimated by Stevens (1997) using a sample of household heads on PSID data over the 1968-1988 period. Differently from the other studies Stevens (1997) identifies worker displacement without relying on mass-layoffs events. A worker is classified as displaced if he leaves the current employer either because a plant or a business is closed or because the worker reports being laid off or fired. As discussed at page 170 of the paper, and given the nature of PSID, the timing of displacement is not precisely identified and a displacement attributed to year t could have in practice occurred in year $t-1$. Losses are measured relative to a group of continuously employed workers. The green dashed line in Figure A5 corresponds to column 4 of Table 4 at page 175 of the paper by Stevens (1997). Jung and Kuhn (2012) proposes a search

model to match the empirical evidence on earnings losses upon re-employment. For the sake of comparison, we plot as a purple dash dotted line the profile of earnings losses generated by the model of Jung and Kuhn (2012) as reported in Figure 6 of their paper.

By comparing empirical evidence, one can observe large variation in the reported estimates. In particular the long-term earnings losses by Davis and von Wachter (2011) are almost twice as large as the estimates in Couch and Placzek (2010) and Stevens (1997), which are remarkably similar between each other.

D.2 Earnings losses in the model

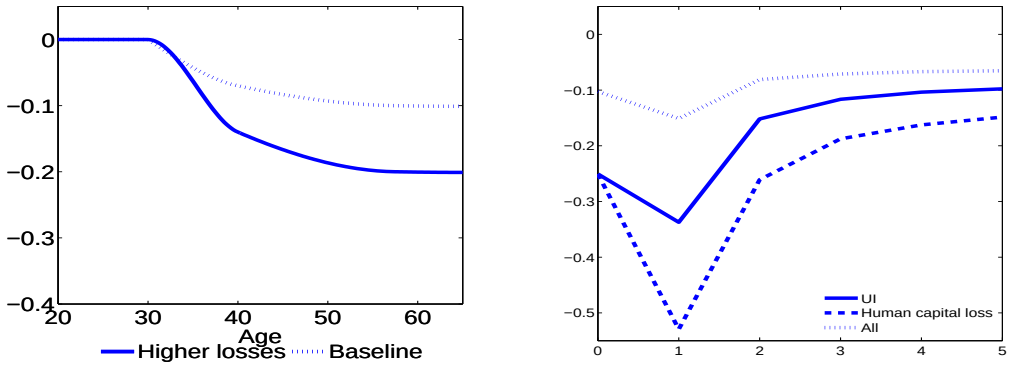
We now construct a measure of earnings losses after displacement in the model. We start defining workers as displaced at t if they were employed in $t-1$ and collect UI benefits in t. This is a natural definition of displacement in the model because as discussed in Couch and Placzek (2010) and Jacobson, LaLonde and Sullivan (1993) there are no long term losses among separators who do not collect UI benefits—independently of whether the worker loses his job during a mass layoff event. We also consider two alternative definitions of displacement: one where workers are defined as displaced whenever they separate from their job, independently of whether they collect UI benefits in a period; another where workers are defined as displaced if they lose their job and experience some loss in their human capital during their first unemployment spell. To measure earnings losses in the model we start simulating the economy and focus on workers who are continuously employed in the same job for at least 12 quarters.[34] Some of these workers get displaced in the next period. For simplicity we assume that workers separate from their job in the fourth quarter of the year. This only affects the earnings losses in the year of displacement but not in following years. This assumption about displacement implies that the annual earnings losses in the year of displacement for workers who collect UI benefits is exactly equal to 25 percent. We later study robustness of results to alternative assumptions about the timing of displacement in the year. For each displaced workers we then simulate 10000 labor market histories until retirement. For each subsequent year after displacement we then averaged out labor earnings across different histories. To be sure, our income definition excludes income from unemployment insurance or capital income, as in the empirical literature. Earnings losses in a year after displacement are calculated as percentage differences in labor income relative to a group of workers who are continuously employed until retirement. We later analyze robustness to alternative control groups. To characterize earnings losses

[34] Jung and Kuhn (2012) focus on a sample of workers with at least 6 years of tenure (24 quarters).

by age, we later perform the same exercise for 4 different age groups depending on whether displaced workers have 25, 35, 45 or 55 years of age. The blue solid line in panel (b) of Figure A5 is the profile of earnings losses in the model for each year after displacement for an average worker in the baseline calibration of the model discussed in Section 4.3 of the paper. The blue dotted line corresponds to the annual earnings losses of workers who separate from their job, independently of whether they collect UI benefits in a period. The blue dashed line is the profile of earning losses for all workers who in the model lose their job and experience some loss in their human capital during their first unemployment spell.

Overall the model tends to under-predict somewhat earnings losses upon displacement as estimated by the literature. At short duration after displacement, differences between data and model are small and they can go either way depending on the definition of displacement. But when looking at long-term losses (more than three years after displacement), the losses generated by the model are around one half of those in the data. But there are strong reasons to believe that the mass-layoff literature (Couch and Placzek 2010, Davis and von Wachter, 2011) tends to systematically over-estimate earnings losses upon displacement. This is first because firms might undergo a mass layoff because of a poor skill quality of their workers—who also experience large average earnings losses—and secondly (and most importantly) because mass layoffs can at least be partly anticipated by workers in the firm and better workers—who have lower earnings losses upon displacement—quit the firm before the mass-layoff event. Autor et al. (2013) (see their Table 8) provide compelling evidence about this latter effect: around one third of the skilled workers in the firm (defined as workers whose pre-displacement wages are in the top tercile of the wage distribution of their age cohort) leave the firm within two years before the mass-layoff and these workers experience virtually no earnings losses. It is also useful to observe that Jacobson, LaLonde and Sullivan (1993) find that workers who separate from their job and who are not part of a mass-lay off, experience initial losses of 26 percent and no losses six years after displacement. In Couch and Placzek (2010) these long term losses are around 7 percent and similar to the model. This is why we think that keeping our calibration as baseline might be appropriate. Moreover the results in the paper are unaffected by the magnitude of wage losses during unemployment. Following the suggestion by one Referee, in Section 7.5 of the paper we study the robustness of the results in the paper once we double the magnitude of wage losses due to human capital depreciation during unemployment. The profile of the optimal age-dependent UI replacement remains virtually unchanged, see Figure 14 in the paper. In this Online Appendix (see Section E.3) we also perform several other robustness exercises, which confirm that the age profile of the optimal UI replacement rate is almost unaffected by changes in either the level or the age profile

of human capital losses during unemployment. Here we just briefly describe the property of the model in terms of earnings losses once we double wage losses during unemployment. The new profile of wage losses, $\overline{\kappa}_n - 1$, corresponds to the blue solid line of panel (a) of Figure A6. The economy is recalibrated to match the targets of Section 4.3 in the paper, see Section E.3 of this Online Appendix for further details. Panel (b) of Figure A6 is analogous to panel (a) of Figure A5, but for the economy with larger human capital losses during unemployment. The new re-calibrated model now matches better the profile of long term earnings losses upon displacement in the data, although long terms losses are still smaller than those found by Davis and von Wachter (2011).



(a) Wage losses: $\overline{\kappa}_n - 1$

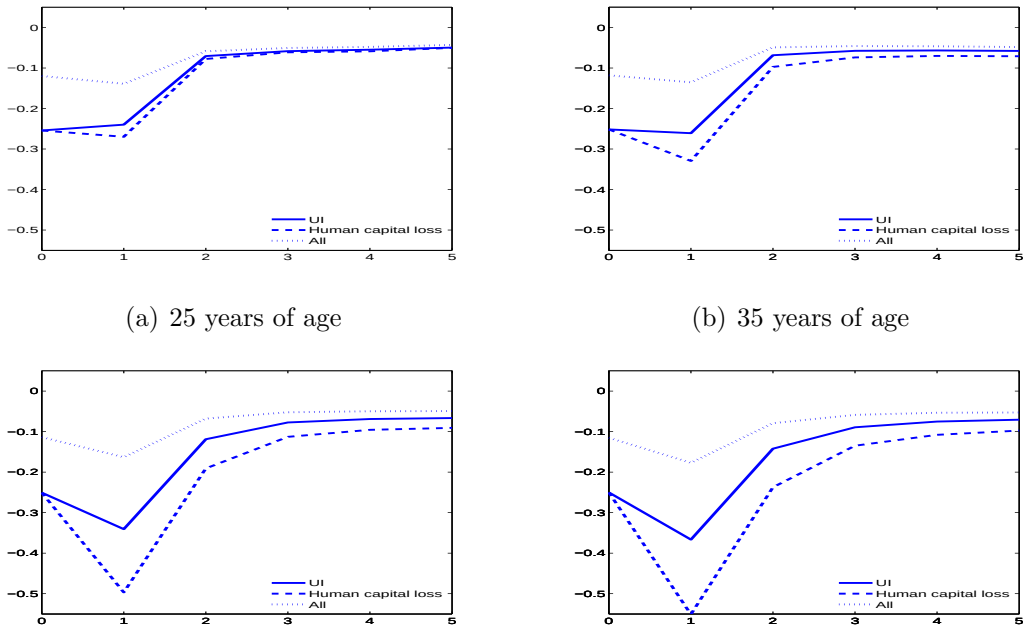
(b) Earnings losses in model with higher wage losses for different definition of displacement

Notes: Panel (a) plots the age profile of wage losses during unemployment in the baseline calibration as a blue dotted line and in the economy where we double wage losses due to human capital depreciation during unemployment, as a blue solid line. Panel (b) is analogous to panel (a) of Figure A5, but where now the lines correspond to the calibration of the model with higher human capital losses during unemployment.

Figure A6: Profile of earnings losses after displacement in re-calibrated model after doubling wage losses during unemployment

D.3 Earnings losses by worker age at displacement

We now characterize the profile of earnings losses upon displacement according to the age of the worker at displacement. As previously anticipated we focus on four different age groups of workers: panel (a) of Figure A7 shows the profile for worker of 25 years of age at displacement, panel (b) focuses on workers of 35 years of age, panel (c) on workers of 45 years of age, and panel (d) on workers of 55 years of age. Each panel is analogous to panel (b) of Figure A5, where we plot the profile of earnings losses for three groups of workers who differ in their definition of displacement: the dotted line corresponds to all workers who separate from



(a) 25 years of age

(b) 35 years of age

(c) 45 years of age

(d) 55 years of age

Notes: Profile of earnings losses after displacement in the model for four different age groups. The parametrization corresponds to the baseline calibration of Section 4.3 in the paper. In each panel we consider three alternative definitions of displacement. The blue solid line corresponds to workers who collect UI benefits at some time during their first unemployment spell; the blue dotted line corresponds to losses of workers who separate from their job independently of whether they collect UI benefits in their first unemployment spell; the blue dashed line are losses for all workers who experience some human capital loss during their first unemployment spell.

Figure A7: Profile of earnings losses after displacement for workers of different age

their job, the solid line corresponds to workers who collect UI benefits, the dashed line corresponds to workers who separate from their job and lose some human capital during their first unemployment spell. Earnings losses increase substantially by age. To better evaluate, how the model reproduces the age variation in the data of earnings losses, Table A3 reports the present discounted value of earnings losses experienced by workers at displacement. Panel A measures losses from year of displacement until retirement, panel B focuses on losses in the next five years after displacement, Panel C focuses on losses in the next three years after displacement. Losses are measured as one minus the ratio of the present discounted value of earnings of displaced workers over the present value of earnings of the control group, which in the model are continuously employed workers. To calculate present values we use a 5 per cent discount rate, which is as Davis and von Wachter (2011). We present results for the previously mentioned four different age groups of workers. For each age group we consider the three alterna-

tive definitions of displacement: all workers who separated from their job (which corresponds to 'All' in the table), workers who separate and collect UI benefits in their first unemployment spell ('UI' in the table) and workers who experience a human capital loss in their first unemployment spell ('HKLoss' in the table). For the sake of comparison we report in column three an analogous calculation by Davis and von Wachter (2011) based on their empirical estimates. We present

Table A3: One minus Ratio of the PDV of earnings of displaced workers over the PDV of earnings of control group

Worker age		Data	Baseline calibration			Re-calibrated model		
Data	Model	All	UI	HKLoss	All	UI	HKLoss	All
A) Life time PDV losses								
21-30	25	-7.8	-7.4	-7.8	-5.6	-7.6	-7.9	-5.7
31-40	35	-6.5	-8.3	-9.6	-5.9	-9.3	-11.2	-6.6
41-50	45	-15.1	-10.6	-13.8	-6.5	-13.0	-18.4	-7.7
51-60	55	-23.1	-14.3	-19.1	-8.7	-17.7	-25.7	-9.9
B) 5 years PDV losses								
21-30	25	-13.4	-13.6	-14.5	-8.3	-13.6	-14.4	-8.3
31-40	35	-12.8	-14.3	-16.8	-8.0	-14.6	-17.7	-7.9
41-50	45	-18.2	-17.6	-23.5	-9.1	-19.6	-28.2	-9.6
51-60	55	-25.3	-19.0	-26.2	-9.9	-22.3	-33.3	-10.7
C) 3 years PDV losses								
21-30	25	-14.5	-18.8	-20.0	-10.6	-18.8	-19.8	-10.5
31-40	35	-12.7	-19.5	-22.7	-10.1	-19.3	-22.9	-9.6
41-50	45	-17.2	-23.8	-31.3	-11.5	-24.7	-34.6	-11.2
51-60	55	-24.1	-25.4	-34.6	-12.4	-27.7	-40.2	-12.4

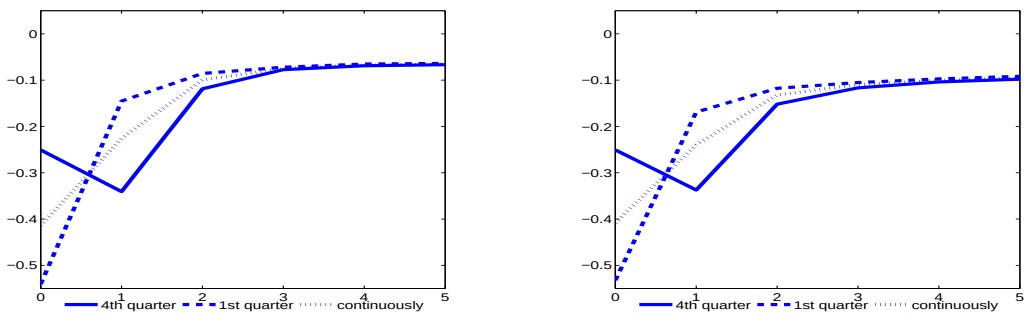
Note: The table reports the value of one minus the ratio of the Present Discounted Value (PDV) of earnings of displaced workers over the PDV of earnings of control group in the model and in the data for different age groups and different time horizons. Losses are calculated for three alternative definitions of displacement: all workers who separated from their job ('All' in table), workers who separate and collect UI benefits in their first unemployment spell ('UI' in table) and workers who experience a human capital loss in their first unemployment spell ('HKLoss' in table). Data correspond to the values from Davis and von Wachter (2011). For an average worker in the population the PDV of earnings losses in Jung and Kuhn (2012), Couch and Placzek (2010) and Stevens (1997) are approximately equal to 0.158, 0.164, and 0.144 respectively. The Re-calibrated model corresponds to the model specification where we doubled wage losses due to human capital depreciation during unemployment as in Figure A6.

results for the baseline calibration of Section 4.3 and for the Re-calibrated model of Section 7.5 where we doubled wage losses due to human capital depreciation during unemployment as in Figure A6. Overall the model matches more closely the losses in present value at short horizons than at long term horizons. At a time horizon of three years, the model matches age variation in earnings losses reasonably accurately when focusing on the sample of workers who collect UI benefits.

At longer time horizons, the model fit is not terrible, especially when focusing on the parametrization with higher wages losses during unemployment. Still allowing for alternative sources of wage losses upon displacement (like accumulation of job specific human capital) could clearly improve the model fit in terms of long term earnings losses upon displacement.

D.4 Sensitivity and robustness of earnings losses results

In this Section we study robustness of results to alternative assumptions about (i) the timing of displacement within a year and (ii) the definition of the control group. In both cases we present results both for the baseline calibration of Section 4.3 and for the recalibrated model with larger wage losses during unemployment of Section 7.5. To save space, here we define workers as displaced if they separate from their job and collect UI benefits. Figure A8 presents the profile of earnings losses upon displacement when we assume that in the year of displacement the worker is always displaced in the first quarter of the year (dashed line), that the worker is displaced in the four quarter of the year (solid line) and that the worker has an equal probability of being displaced in the four quarters of the year (dotted line). As expected, alternative assumptions about the timing of displacement affect the measure of earnings losses mainly in the year of displacement. The effects on subsequent years are instead small.

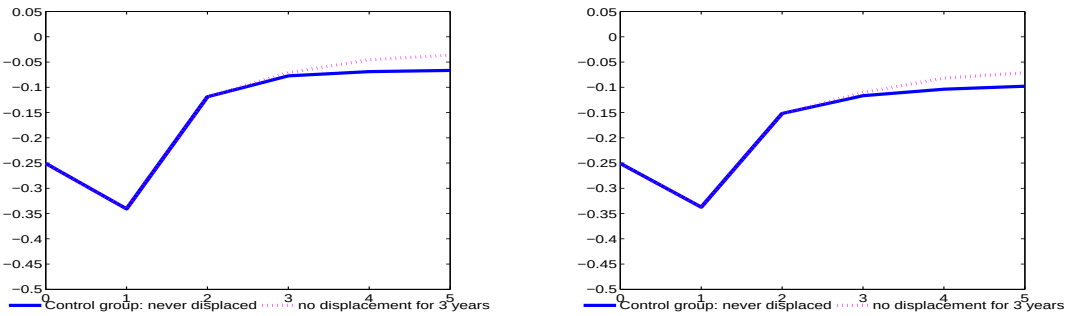


(a) Baseline (b) Recalibrated model

Notes: Profile of yearly earnings losses in the model for alternative assumptions about the timing of displacement in the year of displacement. Panel (a) deals with baseline calibration, panel (b) with the parametrization with higher wage losses during unemployment. The blue solid line corresponds to earnings losses for workers who collect UI benefits in the last quarter of the year, the blue dashed line corresponds to losses when assuming that all workers first collect UI benefits in the first quarter of the year, the blue dotted line corresponds to losses when assuming that workers have an equal probability of collecting UI benefits in all quarters in the year.

Figure A8: Earnings losses from year of displacement: changing the timing of separation

Figure A9 presents the profile of earning losses after displacement when we consider as a control group workers who are employed at t, $t+1$ and $t+2$ where t is the year of displacement of the workers we are measuring losses. This profile corresponds to the red dotted line in the figure. For the sake of comparison we also report the previously reported profile, as a blue solid line, that was obtained using continuously employed workers as a control group. Overall one can see that the choice of the control group affects little the measure of earning losses in the model.



(a) Baseline

(b) Recalibrated model

Notes: Age profile of yearly earnings losses in the model for two alternative control groups. The blue solid line corresponds to earnings losses relative to continuously employed. The red dotted line are losses relative to workers who are employed at t, $t+1$ and $t+2$ where t is the year of displacement of the workers we are measuring losses. Panel (a) deals with baseline calibration, panel (b) with the parametrization with higher human capital losses during unemployment of Section 7.

Figure A9: Earnings losses from year of displacement: changing the control group

E Further details on robustness

Here we provide further details on the robustness exercises discussed in Section 7.

E.1 Age-dependent government budget constraints

In this section we better characterize the economy of Section with age-dependent government budget constraints. The population is divided into N mutually exclusive age groups with maximum age difference k within the group, so that $Nk = \bar{n}_w$. The set of age levels for the ith age group, $i = 1, 2...., N$, is given by $\Gamma_i = \{(i-1)k+1, (i-1)k+2...., ik\}$. Income taxes are the sum of two rates, one used to financed UI benefits expenditures for the specific age group, the other to finance expenditures for retirement pensions, so that $\tau_n = \overline{\tau}_n + \hat{\tau}_0$. Here $\hat{\tau}_0$ is the constant over-time income tax-rate set to finance retirement pensions:

$$\sum_{n=\bar{n}_w+1}^{\bar{n}_r} \beta^n \pi \chi^r(n) = \hat{\tau}_0 \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} w(e) \chi^e(n, de) \tag{68}$$

The age-dependent component of income tax rates $\overline{\tau}_n$ is constant within its corresponding age group so that $\overline{\tau}_n = \hat{\tau}_i \ \forall n \in \Gamma_i$, where $\hat{\tau}_i$ satisfies the following group-i specific budget constraint:

$$\sum_{n \in \Gamma_i} \beta^n \int_{R^+} \rho_n w(e) \chi^u(n, de) = \hat{\tau}_i \sum_{n \in \Gamma_i} \beta^n \int_{R^+} w(e) \chi^e(n, de), \qquad \forall i = 1, ..., N \tag{69}$$

This constraint implies that an increase in benefits for a given age group i can not be financed by increasing tax revenue for another age group. We then search for the age profile of UI replacement rate $\rho \geq 0$ which maximizes worker's wealth at birth W_s subject to the same constraints as before but where now the tax rates $\hat{\tau}_i$'s $i = 0, 1, ..., N$ satisfy the $N+1$ government budget constraints in (68) and (69). In solving the problem we consider age groups of five years, $k = 20$. The resulting optimal age-dependent replacement rate under the age specific government budget constraints specified above corresponds to the solid line in Figure 13.

E.2 Severance payments

We better characterize the economy with age-dependent severance payments in Section 7.4. Upon job displacement workers receive a government transfer equal to $\varsigma_n w(e)$ where worker's age n and worker's human capital e here refer to the last period before job displacement occurs. All the other model assumptions remain as in Section 4. The value of being employed in the economy with severance payments becomes equal to

$$V(n, e, a) \quad = \quad \max_{a' \geq l} u(c^e(n, e, a, a')) + \beta(1 - \delta_n) V(n+1, e+1, a') \tag{70}$$

$$+\beta\delta_n J(n+1, e+1, a' + \varsigma_n w(e)) \tag{71}$$

where the last term incorporates the fact that upon displacement the worker receives a severance pay of $\varsigma_n w(e)$, which increases his wealth at the start of the current job search spell. Nothing else changes relative to (19) and all the other value functions remain as in Section 4, so equations (20)-(23) are left untouched. Of course, the government budget constraint in (24) has to be amended to include severance payments transfers. This yields the following constraint:

$$\sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \rho_n w(e) \chi^u(n, de) + \beta \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \varsigma_n w(e) \delta_n \chi^e(n, de) \tag{72}$$

$$= \sum_{n=1}^{\bar{n}_w} \beta^n \int_{R^+} \tau_n w(e) \chi^e(n, de) - \sum_{n=\bar{n}_w+1}^{\bar{n}_r} \beta^n \pi \chi^r(n). \tag{73}$$

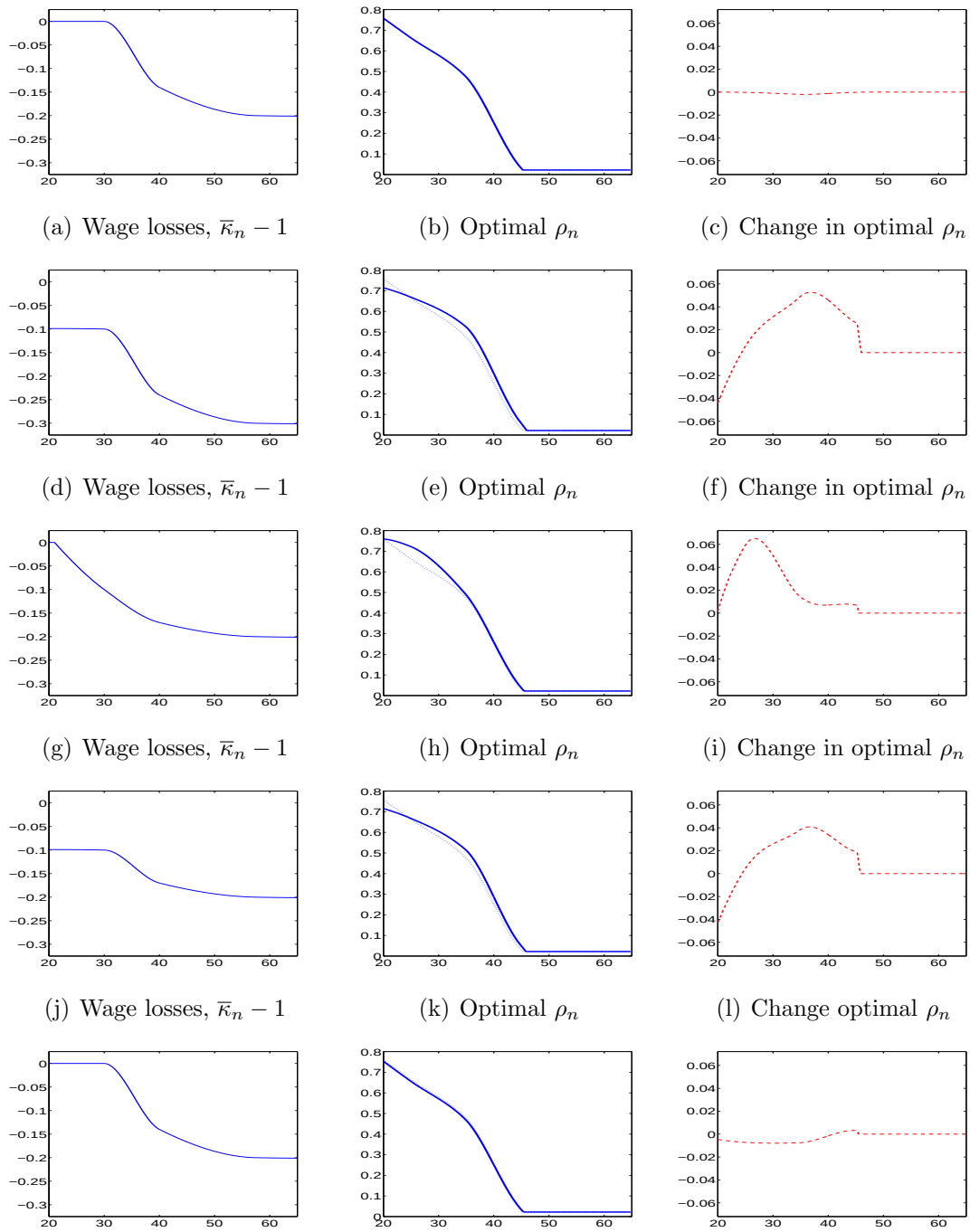
The second term in the first row takes into account that a fraction δ_n of the mass of employed workers of age n and experience e, $\chi^e(n, e)$, will be displaced next period and will receive severance payments $\varsigma_n w(e)$.

We study whether severance payments can improve welfare relative to the economy with optimal age-dependent benefits and taxes. So we keep their age profile as given. To be sure, let ρ_n^* and τ_n^* denote the optimal age profile of benefits and taxes as reported in Figure 10. Here we assume that $\rho_n = \rho_n^*$ and $\tau_n = \tau_n^* + \overline{\tau}$, where $\overline{\tau}$ is needed to keep the government budget constraint in (73) satisfied. We then search for the vectors of severance payments $\varsigma = \{\varsigma_1, ..., \varsigma_{\bar{n}_w}\}$ and the value of the tax rate $\overline{\tau}$ that maximize worker's utility at birth $W_s \equiv J(1, 0, 0)$ subject to the new government budget constraint in (73), workers optimal choices as implied by (20)-(22) and (71), and the feasibility constraint $\rho \geq 0$.[35] Exactly as in Section 6 we assume that ς_n is a cubic spline at the previously defined ten age knots and search for the value at the knots that maximize W_s. When we restrict severance payments to be independent of age $\varsigma_n = \varsigma$, $\forall n$, we find that the optimal constant over age severance payment is $\varsigma = 1.4$. This economy yields welfare gains equivalent to a 3.3 percent increase in life time consumption relative to the baseline economy. This is 0.1 percent higher than in the economy with optimal age-dependent benefits and taxes. When we allow severance payment to vary with age, we virtually find no additional gains (up to the fourth order). We believe that age variation in severance payments yields small welfare gains because severance payments discourage workers from accumulating precautionary savings and thereby are more distortionary than a combination of UI benefits and subsidies to job creation. Since UI benefits together with labor income tax rates can mimic reasonably well the effects of a subsidy to job creation, age variation in severance payments can play little role in improving welfare in our economy.

[35] In the economy we also impose the restriction that $\varsigma_{\bar{n}_w} = 0$, since this transfer would just have the nature of a retirement pension.

E.3 Optimal UI replacement rates and the age profile of wage losses during unemployment

In Section 7.5 of the paper we have seen that the optimal age-dependent UI replacement rate ρ_n remains virtually unchanged once we double the level of wage losses due to human capital depreciation during unemployment $\overline{\kappa}_n - 1$. We now show that this is a general property of the model. Figure A10 shows the profile of the optimal age-dependent UI replacement rate ρ_n for different parametrizations of the level of wage losses during unemployment. The first panel in each row corresponds to the new profile of wage losses upon unemployment $\overline{\kappa}_n - 1$, the second panel shows as a solid line the optimal age-dependent UI replacement rate ρ_n, the third panel plots the difference between the new profile of ρ_n and the profile of ρ_n obtained in the baseline calibration of the model of Section 4.3 in the paper—which for convenience is plotted as a dotted line in the second panel of each row. To simplify the exercise, economies are not recalibrated to match the targets of Section 4.3, except for the parametrization of the economy in the last row, which corresponds to the robustness exercise of Section 7, where all economies are recalibrated to match the targets of Section 4.3. There is some evidence that when wage losses increase across age groups the profile of the optimal age-dependent ρ_n increases for workers of 30 to 45 years of age, while it decreases for the very young. There is also some evidence that when wage losses increase more steeply with age, UI replacement rates tend to increase somewhat for the young. But overall all changes are quantitatively small. In practice this happens because the age profile of the extended redistribution formula $\widetilde{\varrho}$ changes little in response to changes in the profile of $\overline{\kappa}_n - 1$. For example, with higher losses the marginal utility of consumption of the unemployed goes up which pushes up the value of the numerator of $\widetilde{\varrho}$. But with higher losses tax effects also become more important, so $-\frac{\partial T}{\partial b_n}$ goes up, which on balance leaves the overall profile of $\widetilde{\varrho}$ unchanged.



(a) Wage losses, $\overline{\kappa}_n - 1$ (b) Optimal ρ_n (c) Change in optimal ρ_n

(d) Wage losses, $\overline{\kappa}_n - 1$ (e) Optimal ρ_n (f) Change in optimal ρ_n

(g) Wage losses, $\overline{\kappa}_n - 1$ (h) Optimal ρ_n (i) Change in optimal ρ_n

(j) Wage losses, $\overline{\kappa}_n - 1$ (k) Optimal ρ_n (l) Change optimal ρ_n

(m) Recalibration: Wage losses, $\overline{\kappa}_n - 1$ (n) Optimal ρ_n (o) Change in optimal ρ_n

Notes: Optimal age-dependent UI replacement rate ρ_n for different parametrizations of the level of wage losses during unemployment. The first panel in each row corresponds to the new profile of wage losses upon unemployment, the second panel plots as a solid line the optimal age-dependent UI replacement rate ρ_n obtained under he corresponding parametrization, the third panel is the difference between the new profile of ρ_n and the profile obtained in the baseline calibration of the model of Section 4.3 in the paper, which corresponds to the dotted line in the second panel of each row. No economy is recalibrated to match the targets of Section 4.3, except for the parametrization in the last row.

Figure A10: Different profiles of wage losses and the optimal age-dependent UI replacement rate ρ_n