

# A Life Cycle Model of Trans-Atlantic Employment Experiences

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## Abstract

To understand trans-Atlantic employment experiences in the post-World War II era, we enrich the environment of Ljungqvist and Sargent (2008b) in ways that allow skill losses occasioned by involuntary job separations ('turbulence') to have further effects on labor market outcomes. Our model features *ex ante* heterogeneity by having two types of workers who differ in their skill acquisition technologies. These technologies shape workers' long-run career decisions while search frictions in the labor market affect short-run employment outcomes. The model emphasizes labor supply responses near the beginning and end of life and whether early retirements are financed by an individual's savings or by public benefit programs. Increases in minimum wages in Europe explain why youth unemployment has risen more in Europe than in the U.S. Higher turbulence causes long-term unemployment to erupt in Europe, mostly among older workers, but leaves U.S. unemployment unaffected. Increased probabilities of skill losses at times of involuntary job separation interact with workers' subsequent decisions to invest in human capital in ways that generate age-dependent increases in autocovariances of income shocks like those observed by Moffitt and Gottschalk (1995).

KEY WORDS: *Ex ante* heterogeneity, search frictions, human capital, disutility of work, ageing, unemployment benefits, job protection, minimum wage.

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# 1 Introduction

By extending a McCall (1970) search model to include laws of motion for skills that depend on a worker's employment status, Ljungqvist and Sargent (1998) explained how the U.S. escaped the *higher* unemployment that broke out in Europe in the late 1970s because unemployment insurance are limited to six months in the U.S. but have much longer effective durations in Europe. The reason is that increases in microeconomic turbulence that occurred in the late 1970s, modeled as increased skill losses among displaced workers, have small effects on labor market outcomes in the U.S. with its stingy benefits but cause higher unemployment, much of it long term, in Europe with its generous benefits. By extending the model to include ageing workers and government job protection in the form of layoff taxes, Ljungqvist and Sargent (2008b) could attribute *lower* unemployment rates in Europe before 1970 to higher layoff costs in Europe than in the U.S. and also capture the long-term unemployment that erupted among older workers, but not the high youth unemployment.

What about the robustness of those findings to ways of modeling labor market frictions that don't start with the McCall (1970) search model? Ljungqvist and Sargent (2007a) showed that similar economic forces prevail in both a search-island model cast in the Alvarez and Veracierto (2001) mold and a matching model patterned after Mortensen and Pissarides (1999), two structures that include a specific activity called being unemployed and an equilibrium outcome interpretable as frictional unemployment. However, Ljungqvist and Sargent (2007b) showed that the unemployment reducing effects of layoff taxes that prevail in both the search-island model and the matching model in Ljungqvist and Sargent (2007a) do *not* come through in a popular macroeconomic model *without* frictional employment, namely, one with indivisible labor, employment lotteries, and complete consumption insurance markets, a model that builds in the Rogerson (1988)-Hansen (1985) household aggregation theory that Prescott (2006b) advocated for macroeconomics. Furthermore, while the employment lotteries model says that turbulence and generous government unemployment benefits have employment effects *qualitatively* like those in Ljungqvist and Sargent (1998, 2008b), still, when a key disutility of labor parameter is set at the high values commonly used to explain real business cycles, the model deteriorates *quantitatively* because the implied high labor supply elasticity makes aggregate employment implode when publicly supplied unemployment benefits are set at empirically plausible levels.

What role does the Rogerson (1988) aggregation theory play in producing these empirically implausible outcomes? Almost none. By studying what can be achieved with the same specification of preferences, technology, and labor supply indivisibility, but replacing employment lotteries and complete markets with an incomplete market structure that allows individuals to trade single risk-free asset and thereby smooth consumption over time, Ljungqvist and Sargent (2006, 2008a) pinpointed a too high disutility of labor to be the ultimate source of the inability of the model to cope with turbulence and high benefits. They showed that aggregate outcomes are largely unaffected when employment lotteries and complete insurance markets are replaced by incomplete markets and 'time averaging' via life

cycle savings.<sup>1</sup> They also found that maintaining the same high disutility of labor that had been calibrated to fit business cycle observations would, in the incomplete markets model, cause the same excessive sensitivity of employment to benefits that impairs the version of the model with employment lotteries and complete markets.

In his discussion at the NBER, Prescott (2006a) emphasized the research possibilities in macroeconomics opened up by the Ljungqvist and Sargent (2006) incomplete markets analysis: the incomplete markets model redirects attention to how *individuals'* career lengths and retirement dates respond to labor taxes and government benefits.<sup>2</sup> Thus, instead of watching how the director in a representative *family* (really the entire *economy*) chooses what fraction of its members randomly to assign to work at each moment, the incomplete markets model focuses on how individual workers choose fractions of their *lifetimes* to work. These decisions become especially interesting when a model incorporates both privately financed and government financed possibilities for early retirement. Ljungqvist and Sargent (2008a) studied these life-time labor supply decisions in a setting with *ex ante* homogeneous but *ex post* heterogeneous workers and found that the model makes high skill workers owning high financial wealth retire early at their own financial expense, instead of the lower skill workers that we actually see retiring in Europe at government expense. As we shall see, to appreciate how this important force also comes through in the richer life cycle model of this paper, we shall have to understand the additional sources of heterogeneity that we now incorporate in order to put the workers in our model into the rich variety of situations that European and American workers find themselves in as they confront decisions about their life-time financial savings, human capital investments, and participation in labor markets and government support programs.<sup>3</sup>

This paper constructs a life cycle model that is capable of accounting for a variety of microeconomic aspects of observed outcomes that we think are important for fully understanding differing macroeconomic outcomes on the two sides of the Atlantic, including high youth unemployment and the characteristics of those older workers who bail out early in Europe.

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<sup>1</sup>Mulligan (2001) suggested that complete markets with employment lotteries might not be critical in a model with indivisible labor as long as workers can borrow and lend to smooth consumption across alternating periods of work and nonwork. Chang and Kim (2006) analyze an incomplete-market economy with indivisible labor and infinitely-lived agents.

<sup>2</sup>The finitely-lived agents in Ljungqvist and Sargent (2006, 2008a) impart a life-cycle perspective with human capital that Prescott (2006a) liked. Prescott adopted this life-cycle incomplete-market structure in his subsequent work Prescott et al. (2009), that extended the Ljungqvist and Sargent (2006, 2008a) analysis to include a particular intensive margin in workers' labor supply. Rogerson and Wallenius (2007) also introduced human capital, but instead of making human capital endogenous as we do, they assumed that workers face an exogenously given age-specific labor productivity that they want to represent the empirically observed hump-shaped life-cycle earnings profile.

<sup>3</sup>An important theme of the discussion between Ljungqvist and Sargent (2006, 2008a) and Prescott (2006a) is that while the restrictions placed on work histories of individual workers by employment-lotteries complete markets model have not been used to guide econometric studies based on panel data, the incomplete markets model has long been a workhorse there.

## 2 Working parts

We draw from various sources to create an environment in which outcomes are shaped by the life-cycle behavior of ageing agents who are heterogeneous both *ex ante*, because of their abilities to acquire skills, and *ex post*, because of their past luck. Equilibrium objects include panels of individual outcomes that aggregate into economy-wide employment totals that mimic observations in European and U.S. aggregate data. People in our model face incomplete markets and make life-cycle choices about consumption, savings, careers, and job search. Government labor market policies impinge on aggregate outcomes by affecting individuals' budget sets and firms' hiring and retention decisions.

Table 1 summarizes key aspects of our model structure, outcomes they influence, and a small subsample of our references.

Table 1: Working parts and their sources

| Model features                            | Outcomes                                            | Literature                                                     |
|-------------------------------------------|-----------------------------------------------------|----------------------------------------------------------------|
| Random earnings with incomplete markets   | distributions of heterogenous agents                | Bewley (1986)                                                  |
| life cycle                                | consumption and savings profiles                    | Auerbach and Kotlikoff (1987)                                  |
| human capital                             | income profile                                      | Ben-Porath (1967)                                              |
| youthful inexperience                     | job churning                                        | Neal (1999)                                                    |
| indivisible labor with incomplete markets | career length                                       | Ljungqvist and Sargent (2006)                                  |
| search-island                             | unemployment                                        | Lucas and Prescott (1974)<br>Alvarez and Veracierto (2001)     |
| minimum wage                              | youth unemployment                                  | Pries and Rogerson (2005)                                      |
| layoff costs<br>UI                        | suppress unemployment<br>promote unemployment       | Mortensen and Pissarides (1999)                                |
| turbulence                                | volatility of earnings<br>age-dependent persistence | Gottschalk and Moffitt (1994)<br>Moffitt and Gottschalk (1995) |

## 2.1 Sources and motivations for our working parts

### 2.1.1 The life cycle

After Auerbach and Kotlikoff (1987) formulated and simulated models populated with overlapping generations of people who live realistic life spans and travel through lives of work and retirement, subsequent researchers refined aspects of the framework to fit particular empirical observations, for example, the wealth distribution, as studied by e.g. Huggett (1996) and Castaneda et al. (2003). While we note how well our model approximates the age-consumption profiles measured by Gourinchas and Parker (2002) and Fernández-Villaverde and Krueger (2007), we follow Kaplan and Violante (2008) in targeting wealth-income ratios of a segment of the population and don't try to capture the long right tail of the observed wealth distribution.<sup>4</sup> We care about wealth-income ratios of our model population because of the way our model relates a worker's life-cycle consumption and savings targets to his decisions about participating in the labor market. Storesletten et al. (2004) and Guvenen (2007) study time series characteristics of earnings processes that they take as exogenous, while e.g. Domeij and Flodén (2006) and Marcet et al. (2007) make those income processes endogenous outcomes of labor supply decisions. On this dimension, our analysis downplays exogenous transitory income shocks and instead explores a particular kind of *endogenously* generated age-dependent persistent income shock. Specifically, following Heckman et al. (1998), who extended the framework of Ben-Porath (1967), we incorporate on-the-job human capital investments by agents of different types, high and low, intended to represent people with different schooling levels. Following Ljungqvist and Sargent (1998), we assume that human capital can be lost at layoffs. This gives rise to income shocks, the persistence of which depends on agents' subsequent decisions to reinvest in human capital.

### 2.1.2 Youth and inexperience

Inspired by Neal's (1999) study of mobility patterns among young workers searching for suitable careers, we assume that newcomers to the labor market pass through a phase of 'inexperience' and job churning before becoming experienced. For us, becoming *experienced* means gaining access to a Ben-Porath human capital acquisition technology. An inexperienced agent in our model seeks employment both for the wage income it provides now and for the chance it opens to become experienced later.

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<sup>4</sup>There are various ways to induce higher aggregate savings and a more skewed wealth distribution. Castaneda et al. (2003) consider a four-state Markov process on agents' efficiency units of labor where the maximum realization is extremely high but not very persistent, generating large precautionary savings of top earners. De Nardi (2004) explores the importance of bequest motives and intergenerational transmission of ability. Expanding on Quadrini's (2000) dynastic model of entrepreneurship, Cagetti and De Nardi (2006) study how entrepreneurial activity and voluntary bequests can explain observed wealth distributions. Since we model none of these features, the implied physical capital in our model exceeds the agents' aggregate savings. The extra capital can be thought of as being held by a class of agents that is not being explicitly modeled (may that be a domestic dynasty of capital owners or foreign creditors).

### 2.1.3 Search-island structure

The skill acquisition technology shapes workers' long-run career decisions. A search-island model captures search frictions that affect short-run employment outcomes. Building on Lucas and Prescott (1974), Alvarez and Veracierto (2001) assume that workers must search for 'the' labor market where firms create new jobs and destroy old ones that have become unprofitable. Alvarez and Veracierto (2001) postulate that workers and firms are randomly matched and a single wage rate adjusts to let entering job-creating firms expect to break even. Because we have human capital heterogeneity, our market-clearing wage rate applies per efficiency unit of labor, as in the search-island model of Ljungqvist and Sargent (2007a). In the spirit of Alvarez and Veracierto (2001), who control outcomes of interactions within particular firm, worker pairs by imposing that the wage remains constant throughout employment spells, we assume that workers present in the centralized labor market are randomly reassigned across jobs every period. Hence, there is a single wage rate per efficiency unit of labor in an anonymous market for labor. In contrast to Alvarez and Veracierto (2001), who postulate a Markov productivity process at the *firm* level in order to create some firm size dynamics, we assume that each *job* has its own stochastic process. We borrow a representation of productivity shocks from the matching literature, e.g. Mortensen and Pissarides (1999), and have each firm create a single job. Firms destroy a fraction of jobs surviving from last period, forcing a corresponding fraction of the workers who were employed last period to exit the centralized labor market and randomly to be cast into unemployment. After adding workers who decide to quit, our analysis confronts Hall's (1982) stylized facts on the number of jobs held over a typical worker's career as well as the Davis et al. (1996) data on job destruction.

### 2.1.4 Incomplete markets and indivisible labor

Markets are incomplete and people face the dichotomous choice to work or not to work in any given period. There is no intensive margin. Compared to an agent in a complete-market economy who, by trading employment lotteries and contingent consumption claims, chooses a probabilistic labor supply and a deterministic consumption stream, an agent in the incomplete-market economy chooses a *fraction* of her lifetime that is spent working and by smoothing consumption by trading a risk-free asset. By assuming incomplete markets without employment lotteries, we focus on features that endogenously determine timings of labor market careers.

### 2.1.5 Disutility of labor

Following Rogerson (1988) and Hansen (1985), many contributions to the real business cycle literature have fruitfully used a one-period preference specification  $\ln c - Bn$ , where  $c$  is consumption and  $n \in \{0, 1\}$  is labor supplied, and where employment lotteries and a complete set of markets for consumption insurance allow a representative family to smooth consumption in the face of the all-or-nothing labor supply indivisibility at the individual worker level.

The family chooses to send a fraction of its members  $B^{-1}$  to work each period. Prescott (2006b) advocated Hansen-Rogerson employment lotteries plus complete consumption insurance markets as an aggregation theory for macroeconomics. Depending on the application and the occasion, researchers in this tradition have set  $B^{-1}$  equal either to the  $\frac{1}{3}$  fraction of time that a typical individual works during the day or to an employment-population ratio  $\frac{2}{3}$ . Those values of  $B^{-1}$  imply high labor supply elasticities that help fit high employment volatility over business cycle observations but that also cause problems when it comes to generating realistic responses to observed cross-country and cross-time differences in labor taxes and unemployment benefits.

Ljungqvist and Sargent (2006, 2008a) showed that employment lotteries and complete consumption insurance markets are not essential in the sense that similar aggregate outcomes prevail with indivisible labor  $n \in \{0, 1\}$ , incomplete markets, and individually managed ‘time averaging’ of employment with effects on consumption being smoothed via trades of a risk-free asset. Now the instantaneous preferences  $\ln c - Bn$  imply that an isolated person chooses to work a fraction  $T = \min(B^{-1}, 1)$  of her life time. Values of  $B$  greater than 1 again induce the worker to choose a  $T$  interior to  $[0, 1]$ , which now means that she works only a fraction of her potential working life. But Ljungqvist and Sargent (2006, 2008a) find that disutility coefficients  $B$  that yield these interior outcomes again make macroeconomic outcomes overly sensitive to variations in labor tax rates and labor inactivity benefits (such as unemployment insurance), overly sensitive in the sense that realistically calibrated tax and benefit levels cause drastic counterfactual falls in aggregate output in the model economy.

That excessive sensitivity would come through if we were to set a high  $B$  in the present model too. For that reason, in this paper we set a sufficiently low  $B$  so that the typical individual worker is at a work-full-time corner unless something extraordinary occurs to alter her situation. With that starting point, we focus on how losses of human capital late in a worker’s career interact with generous inactivity benefits in ways that can motivate even such strong work-ethic, low- $B$  workers to become discouraged and even to withdraw from active labor market participation.

The time-averaging possibilities discussed in this section have broad ramifications about estimating labor supply elasticities. Many empirical studies infer preference parameters determining labor supply elasticities while imposing exogenous retirement ages. A lesson of Ljungqvist and Sargent (2006, 2008a) is that relaxing that assumption by allowing workers to choose when to begin and end labor market activity, in a model with labor indivisibilities, has effects *throughout* the life cycle that can influence inferences about those preference parameters. Drawing on that insight (see footnote 2), Prescott et al. (2009) and Rogerson and Wallenius (2007) favor parameterizations with high values of  $B$ , in contrast to the present paper that postulates a low value  $B$ , consistent with the finding that U.S. workers with high attachment to the labor market retire at ages 62 and 65 when they become eligible for social security benefits (see e.g. Rust and Phelan (1997)).

### 2.1.6 Government labor market interventions

We study three labor market policies – unemployment insurance, employment protection in the form of layoff costs, and minimum wages. The first two are commonly considered in macro-labor models. The effects of unemployment insurance are typically unambiguous because benefits serve as a subsidy to search for better jobs and to other nonwork activities and hence, unemployment insurance lengthens unemployment spells and increases equilibrium unemployment. The effects of layoff costs are more controversial because they depend on how labor market frictions are modeled. Ljungqvist (2002) explained why layoff costs tend to decrease unemployment in matching and search models, see e.g. Mortensen and Pissarides (1999), Alvarez and Veracierto (2001) and Ljungqvist and Sargent (2007a), but tend to increase unemployment in a representative family model with employment lotteries, see e.g. Hopenhayn and Rogerson (1993) and Ljungqvist and Sargent (2007b). Unemployment falls in the search and matching frameworks because layoff taxes reduce labor reallocation and lock workers into their jobs, lowering *frictional* unemployment.<sup>5</sup> But there is no frictional unemployment in the representative family model with employment lotteries. Here layoff taxes increase unemployment because they make the equilibrium wage fall, prompting the representative family to substitute toward leisure.

The third policy, minimum wages, has received much less attention in macroeconomic models of the labor market. An exception is Pries and Rogerson (2005) who analyze labor market policies in a model where the quality of worker-firm matches is both an inspection good and an experience good. Specifically, when a worker and a firm first meet, they observe a noisy signal of the quality of a potential match; the true quality can be learned only by engaging in production. The imposition of a minimum wage limits the matches that will be kept after the initial signal and then checked out with actual production: the initial signal has to be good enough to make expected match quality high enough to justify the firm's paying at least the minimum wage while waiting to learn the true match quality.

We use a direct approach to capture the same forces and also incorporate the vision of observers of European labor market outcomes like Nickell (1997), who has argued that minimum wages have adverse impacts on youth unemployment but leave prime-age workers largely unaffected. Thus, we consider a level of the minimum wage that constrains the effective opportunity set for low-type inexperienced young workers (we interpret these as having low schooling levels) while not constraining the effective opportunity sets of high type inexperienced agents (we interpret these as having high schooling levels) or of any experienced older workers. For an overview of minimum wages in Europe, see e.g. Dolado et al. (1996) who describe how either government regulations or trade union agreements impose high minimum wages in Europe.

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<sup>5</sup>There are exceptions, most notably Millard and Mortensen (1997), where layoff costs increase unemployment in matching models. Ljungqvist (2002) explains that such contradictory findings are caused by departures from the standard assumption that firms only pay layoff costs for workers whom they have once hired. Millard and Mortensen (1997) assume that firms must also pay layoff taxes after encounters with job seekers who are not hired. That dramatically increases workers' bargaining strength, leading to firms posting fewer vacancies and to higher equilibrium unemployment.

### 2.1.7 Antecedents

This paper continues inquiries into the European employment experience by Ljungqvist and Sargent (1998, 2008b). Bertola and Ichino (1995) and Ljungqvist and Sargent (1998) advanced the thesis that the outbreak of high European unemployment around 1980 was connected to the finding of Gottschalk and Moffitt (1994) of growing instability in earnings of U.S. workers between the 1970s and the 1980s. Bertola and Ichino (1995) interpreted greater earnings instability as reflecting more volatile local demand shocks and showed how a rigid wage and high layoff costs in Europe would lead to higher unemployment in a model with homogeneous workers. In contrast, Ljungqvist and Sargent (1998) imputed part of the increased earnings variability to shocks to individual workers' human capital and showed how generous unemployment benefits in Europe would generate high long-term unemployment among workers who had lost human capital after their last layoff. A counterfactual implication of their analysis was that Europe should already have experienced somewhat higher unemployment than the U.S. before the increase in microeconomic turbulence. But the facts are that European unemployment rates were significantly lower than that of the U.S. in the 1950s and 1960s, as e.g. thoroughly investigated by the U.S. Bureau of Labor Statistics and academics on the President's Committee to Appraise Employment and Unemployment Statistics (1962). Ljungqvist and Sargent (2008b) rationalized these disparate unemployment outcomes over time and across the Atlantic by adding European layoff costs to their model. Under the assumption of unchanging European institutions with generous unemployment benefits and high layoff costs, the analysis attributes low European unemployment in the 1950s and 1960s to layoff costs that reduce inflow rates into unemployment and lengthen average job tenures, while high European unemployment breaks out in turbulent times because generous unemployment benefits dampen the incentives of unemployed workers to adjust their reservation earnings after skill losses and to search diligently for new jobs in which skills could once again be accumulated. Ljungqvist and Sargent (2008b) also extended the analysis in another direction by incorporating stochastic transitions between consecutive age groups. That modification allowed their model to explain why the burden of long-term unemployment falls disproportionately on older workers.

### 2.1.8 New features of the current paper

We enrich the analysis of Ljungqvist and Sargent (2008b) by replacing their single type of (*ex ante* identical) risk-neutral workers who face laws of motion for skills that are affected only by their employment status with more interesting agents who are risk averse and *ex ante* heterogeneous, being of different 'types' that represent different levels of schooling, and who face nontrivial decisions about consumption and investments in financial and human capital. Taking heed of issues raised by Ljungqvist and Sargent (2008a) and discussed in subsection 2.1.5, we calibrate a parameter for the disutility of work and pay special attention to the diverse characteristics of an *ex ante* and *ex post* heterogeneous collection of employed and unemployed workers. We augment government policies to include unemployment benefits of limited duration in the U.S. and a minimum wage in Europe. The minimum wage

makes excess youth unemployment appear in our model but, as in the data, unemployment spells of young workers are relatively short. Long-term unemployment continues to fall disproportionately on older workers. Hairault et al. (2008) and Low et al. (2008) present other structural models of elevated old-age unemployment that they attribute to benefit programs that are available only to older workers.<sup>6</sup> Introducing special benefits for older workers would strengthen effects on labor supplies of older workers, but we choose to work with a streamlined environment in which older workers experience higher long-term unemployment even though workers of all age are entitled to the same benefits (and subject to the same shocks to human capital).

### 2.1.9 Turbulence

Earlier papers (e.g., Ljungqvist and Sargent (1998, 2008b)) have argued that the Gottschalk and Moffitt (1994) and Katz and Autor (1999) evidence for about changing labor income risk indicates an increase in microeconomic turbulence in the sense that we use it here, namely, an increased probability of skill losses for displaced workers. The model here connects to more aspects of this literature, for example, the Moffitt and Gottschalk (1995) evidence about age-dependent changes in persistence in earnings. As we indicate in section XXXX below, our model makes these age-dependent persistence patterns endogenous in ways that reflect workers' decisions about human capital accumulation after involuntary job losses have suddenly reduced their human capital. Broadly speaking, our approach to interpreting changes in the persistence of earnings continues and extends the tradition of Blundell and Preston (1998), who used the cross-equation restrictions in an incomplete markets consumption smoothing model to draw inferences about exogenous income processes from shadows cast on consumption. We say 'extend' because our model makes earnings processes endogenous: cross-equation restrictions make consumption and earnings profiles carry information about parameters of objects that pin down human capital acquisition technologies, search frictions, and government social insurance arrangements.

## 3 The Model Environment

In each period, there arrives a new cohort of agents who are alive for at most  $T$  periods. Agents of age  $t < T$  face a probability  $m_t$  of surviving until next period. Conditional on surviving, an agent is of working age during her first  $T^n < T$  periods of life and must be retired during her remaining  $T - T^n$  periods. Age  $T^n$  is a mandatory retirement age, but

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<sup>6</sup>To represent the favorable treatment of older workers in French unemployment insurance in the early 1990s, Hairault et al. (2008) postulate higher benefits for workers above the age of 55 in their model. Low et al. (2008) study the employment effects of disability insurance in the U.S. and assume that only workers above the age of 50 are eligible to apply. There is no such age limit in the U.S. but the restriction seems to be crucial because their model makes participation drop off sharply at age 50. One might suspect that the number of workers on disability in the model, not reported in the paper, might be at odds with the data. According to Autor and Duggan (2003), 3.7% of Americans in ages 25-64 received disability insurance benefits in 2001.

a worker is also free effectively to retire earlier by withdrawing from active labor market participation. An unemployed agent of working age has access to a search technology like the one posited by Alvarez and Veracierto (2001). By expending a search effort  $s \in [0, 1]$ , an agent finds ‘the’ centralized labor market next period with probability  $S(s)$ . The type of job she encounters depends on whether the agent is in the first or second phase of her labor market career, namely, an initial phase of ‘inexperience’ or a later phase of ‘experience’.

There is *ex ante* heterogeneity because two types of workers  $i = H, L$  are differentiated according to (1) when they are inexperienced, the probability distribution  $G_i(n)$  of efficiency units of labor, and (2) when they are experienced, the parameters of a skill acquisition stochastic matrix  $H_i^n(h, \bar{h}; \ell)$  that governs stochastic transitions from skill level  $h$  to skill level  $\bar{h}$ , and an initial level  $h_{o,i}$ .

An inexperienced agent of type  $i$  who finds the labor market draws a job offer to supply  $n$  efficiency units of labor from a probability distribution  $G_i(n)$ . If the offer is accepted, the efficiency units remain constant as long as the agent retains the job and does not become experienced. For the sake of brevity, we refer to a worker’s ‘job’ but, as will become clear in section 3.2, it would be more accurate to say a worker’s ‘spell in the labor market’. At the beginning of a period, nature destroys jobs held by inexperienced agents with probability  $\tilde{\lambda}$ , and firms destroy further jobs with probability  $q$ . If a job survives, an inexperienced agent faces a probability  $\pi$  that she becomes experienced and enters the second phase of her labor market career. Next, agents whose jobs have not been destroyed decide whether to keep their jobs or quit and search for new ones. The efficiency units of an agent who just became experienced and did not quit is  $n(h_{o,i}, l)$ , where  $h_{o,i}$  is the initial human capital of an agent of type  $i$  and  $l$  is the time that the agent devotes to acquiring human capital.<sup>7</sup>

At the beginning of a period, nature destroys jobs held by experienced agents with probability  $\lambda \leq \tilde{\lambda}$  and firms destroy more with probability  $q$ .<sup>8</sup> If a job survives and the

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<sup>7</sup>As described in section 2.1.2, the phase of ‘inexperience’ is intended to capture the observed job churning of young workers as studied by Neal (1999) who formulated a search model in which the worker’s productivity is the sum of two components – a career match and a job match. At the beginning of each period, the worker may draw new values of both components, or she may retain her career and only draw a new job. The optimal career-job strategy has the worker focusing on finding a suitable career before searching for an ideal job. While this theory rationalizes churning, it does not explain lengths of employment spells during that process because values of careers and jobs are known as soon as they are drawn. One way to embellish the environment would be to incorporate learning like Pries and Rogerson (2005), as mentioned in section 2.1.6. For tractability, Pries and Rogerson assume that successive observations of the worker’s output is the sum of a true underlying match quality and noise represented by a uniformly distributed i.i.d. random variable, so that learning takes a simple “all-or-nothing” form. Unfortunately, that tractability comes at the price of an unrealistically large variation in output. For example, in Pries and Rogerson’s preferred parameterization of two possible match qualities, bad and good, the corresponding ranges of realized outputs, not reported in the paper, are  $[-2.46, 4.46]$  and  $[-1.56, 5.36]$ , respectively, where realizations in the disjoint set perfectly reveal the true match quality and others are uninformative. Given the problematic nature of these models for quantitative analysis, we opted for our reduced-form representation of the phase of inexperience with the expectation that similar outcomes would arise in a more fully specified model with features from Neal (1999), and Pries and Rogerson (2005).

<sup>8</sup>Compared to experienced workers, we subject inexperienced workers to an additional risk of job termination,  $(\tilde{\lambda} - \lambda) \geq 0$ , in order to induce additional job churning in the initial phase of inexperience.

worker does not quit, an employed experienced agent chooses how much time  $l \in [0, 1]$  to spend on human capital investments. The agent's current labor supply in efficiency units,  $n(h, l) = h(1 - l)$ , declines in  $l$ . By devoting  $l$  this period, she acquires a type-dependent probability  $H_i^n(h, \bar{h}; l)$  that her skill at the beginning of next period is  $\bar{h}$ . But before it is used in production, an experienced worker's skill level  $\bar{h}$  can be adversely affected because with probability  $\lambda$ , an employed agent experiences an exogenous layoff and her beginning-of-period skill is subject to yet another transition probability, as given by  $H_i^\lambda(\bar{h}, h')$ .<sup>9</sup>

### 3.1 Preferences

We assume that preferences are separable between consumption and leisure,

$$E_0 \sum_{t=0}^T \beta^t [\log c_t - B_t], \quad \text{with } B_t \in \{B^u(s), B\}, \quad (1)$$

where we have also adopted the logarithmic form for the utility of consumption that would be consistent with balanced growth if there were technological progress. However, our term for the disutility of effort includes both a disutility of search when unemployed,  $B^u(s)$  that is increasing in  $s$ ; and a disutility of work,  $B$ . The disutility of work has no intensive margin since our agents can work either full time or not at all.

### 3.2 Technology

The production technology is the same as in Ljungqvist and Sargent (2007a). However, we make an important change in the process that randomly matches workers with firms. Ljungqvist and Sargent (2007a) assumed that jobs newly created by firms are matched randomly with workers who have just found the centralized labor market, but that ongoing firm-worker matches continue this period unless they are broken either by a worker quitting or dying or by a firm's decision to shut down a job. To facilitate analysis, in this paper we assume that *all* pre-existing 'job sites', including both newly created and continuing ones, are randomly re-matched with workers who find themselves in the centralized labor market, regardless of whether these workers are newly arrived or old-timers. This assumption means that there are no 'jobs' in the sense of long-term relationships between particular firms and particular workers. Instead, to a worker a 'job' refers to her current spell in the centralized

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<sup>9</sup>As discussed in section 2.1.1, we focus on human capital losses at layoffs, encoded in transition probability  $H_i^\lambda(\bar{h}, h')$ , as a source of earnings shocks for experienced workers. We use the transition probability for skills during employment,  $H_i^n(h, \bar{h}; l)$ , only to translate investment outcomes from a deterministic Ben-Porath technology in continuous space to our finite grid of human capital points, which also imposes uncertainty on workers' human capital investment outcomes. Specifically, appendix A describes how probabilities are assigned to the pair of human capital points that brackets an outcome determined by the Ben-Porath technology. While acknowledging the potential for considering richer stochastic processes in our framework to match earnings observations over the life cycle of workers, we defer that to future research in order to make the current focus of our inquiry as transparent as possible.

labor market, while to a firm a ‘job’ is an ongoing profitable employment opportunity that is occupied over time by different people who vary randomly in both their skill and experience levels. A process randomly matches a firm job site with someone drawn from the pool of workers who are present in the centralized labor market. The firm pays that randomly drawn worker a competitively determined wage times that worker’s particular supply of efficiency units of labor.

This specification is in the spirit of Lucas and Prescott (1974) and Alvarez and Veracierto (2001), who created manageable environments in which workers search but a unique wage rate per efficiency unit of labor is nevertheless determined competitively. We have designed our environment to confront firms with interesting job creation-destruction decisions and workers with interesting search and quitting decisions, while also allowing an equilibrium wage to equate an aggregate demand with an aggregate supply of efficiency units of labor.

Incurring a startup cost  $\mu$  at time  $t$  allows a firm to create a job at  $t+1$  with productivity level  $z = z_{\text{initial}}$ . The productivity level then follows a Markov process,  $Z(z, z')$ . At the beginning of a period, nature exogenously destroys jobs with probability  $\lambda$ ; then firms may decide to terminate others.

The firm’s production function for a job is

$$F(z_t, k_t, n_t) = \exp(z_t) k_t^\alpha n_t^{1-\alpha}, \quad \text{with } \alpha \in (0, 1), \quad (2)$$

where  $z_t$  is the current job-specific productivity level,  $k_t$  is physical capital that depreciates at the rate  $\delta$ , and  $n_t$  is efficiency units of labor supplied by the worker filling the job in that period.

The timing of events is as follows. At the very beginning of a period, a fraction  $\lambda$  of all jobs from last period are randomly and exogenously destroyed. Next, firms with surviving jobs observe productivity levels and then have to decide whether to proceed with production or to terminate jobs. This decision is taken under a veil of ignorance about the identity of the worker who will fill a particular job in the current period. That means that all firms choose the same reservation productivity level  $\bar{z}$ . In this way, firms terminate a fraction  $q$  of jobs that survived after the exogenous probability  $\lambda$  termination shock. Thereafter, all remaining jobs are randomly assigned to workers present in the centralized labor market. Firms observe their workers’ efficiency units of labor and then rent amounts of capital that maximize profits. Workers receive a market-clearing wage rate  $w$  per efficiency unit of labor, i.e., a wage rate at which newly created jobs expect to break even. The real wage per efficiency unit of labor adjusts to ensure that all workers in the central labor market are employed and that newly created jobs expect to break even.

The following remarks are intended to clarify the connections between firms and workers. Both firms and workers are affected by the exogenous job destruction rate  $\lambda$  at the beginning of a period. A fraction  $\lambda$  of all firms’ jobs from last period are randomly destroyed, and a fraction  $\lambda$  of all surviving employed workers from last period who have not reached retirement age are randomly separated from the centralized labor market. Similarly, firms’ endogenous destruction of jobs at the rate  $q$  imparts a corresponding fraction of forced separations from the centralized labor market among employed workers from last period. In contrast, workers

who leave the centralized labor market by their own choice, i.e., workers who quit, have no direct impacts on firms since firms' jobs are randomly matched in each period with remaining workers and newcomers in the centralized labor market. Note that the additional exogenous separation rate among inexperienced workers,  $(\tilde{\lambda} - \lambda) \geq 0$ , also have no direct consequences for firms.

### 3.3 Government policy

The government's labor market policy consists of three instruments. First, workers who are exogenously or endogenously laid off by firms are entitled to unemployment benefits for the maximum duration of  $d_{\max}$  periods. The function  $\Gamma(e)$  maps lost earnings  $e$  into benefits that are paid until the worker either finds a new job or retires. Second, firms pay a job destruction tax  $\Omega$  for each job that they endogenously terminate. Third, the government imposes a minimum wage. Specifically, a job cannot pay less than  $e_{\min}$ .

The government taxes labor earnings including unemployment benefits at the rate  $\tau_n$ , and interest earnings at the rate  $\tau_k$ . Labor earnings are also subject to the payroll (social security) tax at the rate  $\tau_p$ . Lump-sum transfers of  $\epsilon$  and  $\hat{\epsilon}$  are paid to working-age agents and retirees, respectively. The difference between total tax revenues and payments for unemployment benefits and lump-sum transfers is spent on public consumption  $X$ .<sup>10</sup>

## 4 The model

### 4.1 Workers' activities

Tables 2, 3, 4, and 5 show definitions of states, decisions, and government policy parameters, key objects, and value functions for several classes of agents, there being multiple types within each class that are differentiated by age and other state variables. The value functions are indexed by the age  $t$  of the worker. An inexperienced worker bears a tilde on his value function and has state  $a, \gamma, d, t$  when he is unemployed and  $a, n, t$  when he is employed, where  $a$  denotes his assets,  $\gamma$  his past-earnings-related unemployment compensation,  $d$  elapsed duration of unemployment (this is relevant for keeping track of eligibility to UI benefits that have limited duration),  $t$  is age, and  $n$  is an inexperienced worker's efficiency units of labor. Value functions of experienced workers of age  $t$  bear no tilde's and have state  $a, h, t$  when employed and  $a, h, \gamma, d, t$  when unemployed, where  $h$  denotes a worker's human capital level. Persons of age  $t > T^n$  acquire a hat on their value function, are retired, and have state  $a, t$ .

By searching for work when he or she is unemployed, an inexperienced workers invest in the only form of human capital available to him or her, namely, occupying a job with the level of labor efficiency units  $n$  that he or she previously had drawn. Holding a job opens a chance for the inexperienced worker to become experienced next period. A new experienced

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<sup>10</sup>Our calibration strategy is to match tax rates, benefits and transfers, while letting  $X$  serve as a residual. Hence, the computation of an equilibrium would not involve any loop with respect to the government budget constraint.

Table 2: States and decisions

| Variable | Meaning                          |
|----------|----------------------------------|
| $a$      | assets                           |
| $\gamma$ | UI benefits                      |
| $d$      | elapsed duration of unemployment |
| $t$      | age                              |
| $n$      | efficiency units of labor        |
| $h$      | human capital                    |
| $i$      | skill type                       |
| $c$      | consumption                      |
| $s$      | search intensity                 |
| $l$      | investment in skills             |
| $z$      | firm productivity shock          |
| $k$      | physical capital                 |

Table 3: Government policies

| Variable         | Meaning                                             |
|------------------|-----------------------------------------------------|
| $d_{\max}$       | UI maximum duration                                 |
| $\Gamma(e)$      | UI of worker with last-employed earnings $e$        |
| $\Omega$         | job destruction tax when firms destroy endogenously |
| $e_{\min}$       | minimum wage                                        |
| $\tau_n$         | labor tax rate                                      |
| $\tau_p$         | social security tax rate                            |
| $\tau_k$         | capital tax rate                                    |
| $\epsilon$       | benefits, working age                               |
| $\hat{\epsilon}$ | benefits, retirees                                  |
| $X$              | public consumption                                  |

Table 4: Value functions

| Value function                   | phase of life             | decisions                  |
|----------------------------------|---------------------------|----------------------------|
| $\tilde{V}_i^u(a, \gamma, d, t)$ | inexperienced, unemployed | $c, a', s$                 |
| $\tilde{V}_i^n(a, n, t)$         | inexperienced, employed   | $c, a'$                    |
| $V_i^u(a, h, \gamma, d, t)$      | experienced, unemployed   | $c, a', s$                 |
| $V_i^n(a, h, t)$                 | experienced, employed     | $c, a', l$                 |
| $\hat{V}(a, t)$                  | old, retired              | $c, a'$                    |
| $V^f(z)$                         | firm                      | $\{\text{stay, exit}\}, k$ |

worker of type  $i$  begins with an initial level  $h_{o,i}$  of the human capital that will form part of his state for the rest of his working life. He or she can influence the evolution of human capital by devoting time  $l$  to acquiring it.

## 5 Bellman equations

### 5.1 Agents' problems

Two types of worker, indexed by  $i = H, L$ , are distinguished by (1) the distributions  $G_i(n)$  of effective labor supplies that they draw when inexperienced, and (2) stochastic skill acquisition technologies that we characterize in terms of type- $i$ -specific probabilities  $H_i^n(h, \bar{h}; \ell)$  and a function  $n(h, l) = h(1 - l)$ , and (3) initial levels of human capital  $h_{o,i}$  (upon becoming experienced).

### 5.2 Retired people

The value function for a retired agent is

$$\hat{V}(a, t) = \max_{c, a'} [\log(c) + \beta m_t \hat{V}(a', t + 1)] , \quad (3)$$

subject to

$$\begin{aligned} c + a' &\leq [1 + (1 - \tau_k)r]a + \hat{e} , \\ c, a' &\geq 0 . \end{aligned}$$

Policy functions  $\hat{c}(a, t)$  and  $\hat{a}(a, t)$  give optimal levels of consumption and savings, respectively.

Table 5: Probabilities

| Object                     | Interpretation                                                                                                                        |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| $G_i(n')$                  | prob. dist. of efficiency units of labor $n'$ , from which an inexperienced worker of type $i$ draws                                  |
| $S(s)$                     | prob. of finding labor market, given search intensity $s$                                                                             |
| $m$                        | survival probability                                                                                                                  |
| $\pi$                      | prob. inexperienced becomes experienced                                                                                               |
| $\lambda$                  | prob. job of experienced worker is destroyed exogenously                                                                              |
| $\tilde{\lambda}$          | prob. job of inexperienced worker is destroyed exogenously                                                                            |
| $q$                        | prob. firm chooses to destroy job endogenously                                                                                        |
| $H_i^n(h, \bar{h}; l)$     | prob. of $\bar{h}$ beginning of next period, for an employed worker with current human capital $h$ and investment level $l$           |
| $H_i^\lambda(\bar{h}, h')$ | extra $\downarrow$ transition $h$ following exogenous termination;<br>prob. of $h'$ , for a worker with beginning-of-period $\bar{h}$ |

### 5.3 Experienced workers

The value function of an experienced agent who has accepted an employment opportunity is

$$\begin{aligned}
V_i^n(a, h, t) = & \max_{c, a', l} \left[ \log(c) - B^n + \beta m_t \sum_{\bar{h}} H_i^n(h, \bar{h}; l) \right. \\
& \cdot \left( \lambda \sum_{h'} H_i^\lambda(\bar{h}, h') V_i^u(a', h', \Gamma(w n(h, l)), 1, t + 1) \right. \\
& + (1 - \lambda) q V_i^u(a', \bar{h}, \Gamma(w n(h, l)), 1, t + 1) \\
& \left. \left. + (1 - \lambda)(1 - q) \max \left\{ V_i^n(a', \bar{h}, t + 1), V_i^u(a', \bar{h}, 0, 1, t + 1) \right\} \right) \right] \quad (4)
\end{aligned}$$

subject to

$$\begin{aligned}
c + a' & \leq [1 + (1 - \tau_k)r] a + (1 - \tau_n - \tau_p) w n(h, l) + \epsilon, \\
c, a' & \geq 0, \text{ and } l \in [0, 1 - e_{\min}/(wh)].
\end{aligned}$$

Policy functions  $c_i^n(a, h, t)$ ,  $a_i^n(a, h, t)$ , and  $l_i(a, h, t)$  give optimal levels of consumption, savings and time spent on human capital accumulation, respectively.

The value function for an experienced unemployed agent is

$$V_i^u(a, h, \gamma, d, t) = \max_{c, a', s} \left[ \log(c) - B^u(s) + \beta m_t \right]$$

$$\begin{aligned} & \cdot \left( S(s) \max \left\{ V_i^n(a', h, t+1), V_i^u(a', h, \gamma', d+1, t+1) \right\} \right. \\ & \left. + [1 - S(s)] V_i^u(a', h, \gamma', d+1, t+1) \right) \end{aligned} \quad (5)$$

subject to

$$\begin{aligned} c + a' &\leq [1 + (1 - \tau_k)r] a + (1 - \tau_n) \gamma + \epsilon, \\ c, a' &\geq 0, \text{ and } s \in [0, 1]. \end{aligned}$$

Note that  $\gamma' = \gamma$  if  $d < d_{max}$  and 0 otherwise. Policy functions  $c_i^u(a, h, \gamma, d, t)$ ,  $a_i^u(a, h, \gamma, d, t)$ , and  $s_i(a, h, \gamma, d, t)$  give optimal levels of consumption, savings and time spent on job search, respectively.

In the last period before retirement, the agent would optimally set  $l = 0$  if employed and  $s = 0$  if unemployed, and all the continuation value functions in Bellman equations (4) and (5) are then replaced by  $\hat{V}(a', t+1)$ .

## 5.4 Inexperienced workers

The value function of an inexperienced type  $i$  agent who has accepted an employment opportunity is

$$\begin{aligned} \tilde{V}_i^n(a, n, t) &= \max_{c, a'} \left\{ \log(c) - B^n \right. \\ &+ \beta m_t [\tilde{\lambda} + (1 - \tilde{\lambda})q] \tilde{V}_i^u(a', \Gamma(wn), 1, t+1) \\ &+ \beta m_t (1 - \tilde{\lambda})(1 - q) \left[ \pi \max \{ V_i^n(a', h_{o,i}, t+1), V_i^u(a', h_{o,i}, 0, 1, t+1) \} \right. \\ &\left. \left. + (1 - \pi) \max \{ \tilde{V}_i^n(a', n, t+1), \tilde{V}_i^u(a', 0, 1, t+1) \} \right] \right\} \end{aligned} \quad (6)$$

subject to

$$\begin{aligned} c + a' &\leq [1 + (1 - \tau_k)r] a + (1 - \tau_n - \tau_p) w n + \epsilon, \\ c, a' &\geq 0. \end{aligned}$$

Policy functions  $\tilde{c}_i^n(a, n, t)$  and  $\tilde{a}_i^n(a, n, t)$  give optimal levels of consumption and savings, respectively.

The value function for an inexperienced unemployed agent is

$$\begin{aligned}
\tilde{V}_i^u(a, \gamma, d, t) = & \max_{c, a', s} \left[ \log(c) - B^u(s) + \beta m_t S(s) \sum_{n'} G_i(n') \right. \\
& \cdot \left( I(w n' \geq e_{\min}) \max \left\{ \tilde{V}_i^n(a', n', t+1), \tilde{V}_i^u(a', \gamma', d+1, t+1) \right\} \right. \\
& \left. \left. + I(w n' < e_{\min}) \tilde{V}_i^u(a', \gamma', d+1, t+1) \right) \right. \\
& \left. + \beta m_t [1 - S(s)] \tilde{V}_i^u(a', \gamma', d+1, t+1) \right] \quad (7)
\end{aligned}$$

subject to

$$\begin{aligned}
c + a' & \leq [1 + (1 - \tau_k)r] a + (1 - \tau_n) \gamma + \epsilon, \\
c, a' & \geq 0, \text{ and } s \in [0, 1],
\end{aligned}$$

where  $I(\cdot)$  is an indicator function that is equal to one if the statement in parentheses is true and zero otherwise.  $\gamma' = \gamma$  if  $d < d_{\max}$  and 0 otherwise. Policy functions  $\tilde{c}_i^u(a, \gamma, d, t)$ ,  $\tilde{a}_i^u(a, \gamma, d, t)$ , and  $\tilde{s}_i(a, \gamma, d, t)$  give optimal levels of consumption, savings and time spent on job search, respectively.

If the agent is still inexperienced in the last period before retirement, she would optimally set  $s = 0$  if unemployed, and all the continuation value functions in Bellman equations (6) and (7) are then replaced by  $\hat{V}(a', t+1)$ .

## 5.5 Firm's problem

The value function of an existing firm with the productivity level of  $z$  is

$$V^f(z) = \max \left\{ E_n \left[ \tilde{V}^f(n, z) \right], -\Omega \right\}, \quad (8)$$

$$\tilde{V}^f(n, z) = \max_k \left\{ \exp(z) k^\alpha n^{1-\alpha} - wn - (r + \delta)k \right\} + \frac{1-\lambda}{1+r} \sum_{z'} Z(z, z') V^f(z'). \quad (9)$$

Associated with the solution to an existing firm's optimization problem is a reservation productivity  $\bar{z}$  that satisfies

$$E_n \left[ \tilde{V}^f(n, \bar{z}) \right] = \Omega. \quad (10)$$

The break-even condition for starting a new firm is

$$\mu = \frac{1}{1+r} E_n \left[ \tilde{V}^f(n, z_{\text{initial}}) \right]. \quad (11)$$

In a stationary equilibrium, firms that are exogenously destroyed or endogenously terminated are replaced by the entry of new firms that possess the initial productivity level of  $z_{\text{initial}}$ .

## 6 Parameterization

We parameterize the model to tranquil times when agents set their sights on working until the mandatory retirement age. Hence, we set the critical parameter  $B$  governing the disutility of work low enough to solicit such a lifetime labor supply. We say more about the implied value of  $B$  below. While all parameters jointly affect the equilibrium outcomes of our model, we will proceed to discuss one or a couple parameters at a time when they are mainly responsible for a specific feature of an equilibrium. In graphs that explore the sensitivity of equilibrium outcomes to a particular parameter, we hold all other parameters constant at benchmark values.

After adopting standard assumptions on the aggregate production function, we approach parameterization by dividing the model into four blocks: (i) the life-cycle of experienced workers with respect to consumption and investments in financial and human capital, (ii) search and job creation in the centralized labor market, (iii) the initial phase of inexperience of young workers, and (iv) labor market policies. The implications of selecting parameter values for the disutility of work and different degrees of turbulence are saved to the last.

The aggregate technology is represented by a Cobb-Douglas production function with physical capital and efficiency units of labor as inputs. The capital share parameter is  $\alpha = 0.33$ , and the depreciation rate is  $\delta = 0.06$ . We assume an interest rate of  $r = 0.04$  that also determines the marginal productivity of labor in each firm. We compare shares of the implied capital stock that are owned by the low-type and high-type workers, respectively, to the data on asset holdings for those income groups.

We initially calibrated the life-cycle dynamics of experienced workers at an annual frequency and then converted to a bimonthly model period. Regarding the Ben-Porath technology for human capital acquisition, ...

**I.** Life cycle dynamics of experienced agents (putting frictions and turnover aside) – age profiles of earnings (Ben-Porath), consumption and savings ( $\beta$  and mortality rates). Compare to aggregate capital.

**II.** Average jobs over the lifetime and job destruction rates. (Hall (1982), Davis and Haltiwanger (1990))

**III.** Search technology. The search disutility is  $B^u(s) = -\bar{B}^u[(1-s)^\zeta - 1]/\zeta$  as in Alvarez and Veracierto (2001). The parameter  $\bar{B}^u$  is set as  $\bar{B}^u = B\zeta$ , where  $B$  is the disutility of work, so searching full time (i.e.  $s = 1.0$ ) generates disutility  $B$ , corresponding to the disutility of full time work. Job finding probability is  $S(s) = \xi s$ .

**IV.** Policies: UI with 60% replacement on both continents but with different duration in the U.S. (6 months) and in Europe (unlimited). For layoff costs, see figure 2.

**V.** The disutility of work. Figure 3.

**VI.** Turbulence. Figure 4.

Table 6: Parameter values (rates and probabilities on an annual basis); bi-monthly model period and low-type workers constitute 70% of the population

| Parameter                  | Value                                                                                                                                                              |
|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\beta$                    | 0.98                                                                                                                                                               |
| $B$                        | 0.30                                                                                                                                                               |
| $\zeta$                    | 0.98                                                                                                                                                               |
| $\xi$                      | 0.8                                                                                                                                                                |
| $\alpha$                   | 0.33                                                                                                                                                               |
| $\delta$                   | 0.06                                                                                                                                                               |
| $\lambda$                  | 0.03                                                                                                                                                               |
| $\tilde{\lambda}$          | 0.65                                                                                                                                                               |
| $\pi$                      | 0.33                                                                                                                                                               |
| $\Gamma(e)$                | 60% replacement ratio                                                                                                                                              |
| $d_{\max}$                 | 6 months (U.S.),<br>unlimited (Europe)                                                                                                                             |
| $e_{\min}$                 | 0 (Europe in tranquil times and U.S.)<br>60% of low-type worker earnings (Europe in turbulent times)                                                               |
| $\Omega$                   | 0 (U.S.)<br>3 months of low-type worker earnings (Europe)                                                                                                          |
| $\hat{e}$                  | 0.5, i.e., a net-of-tax replacement rate for low/high-type workers of 62.7% / 33.3% in U.S.; 78.3% / 41.7% in Europe                                               |
| $\tau_n$                   | 0.15 (U.S.),<br>0.30 (Europe)                                                                                                                                      |
| $\tau_p$                   | 0.10                                                                                                                                                               |
| $\tau_k$                   | 0.15                                                                                                                                                               |
| $\nu$                      | 0.8                                                                                                                                                                |
| $A_i$                      | 0.05046 (for the low type)<br>0.06554 (for the high type)                                                                                                          |
| $h_{o,i}$                  | 1.0 (for the low type)<br>1.778 (for the high type)                                                                                                                |
| $H_i^n(h, \bar{h}; l)$     | see appendix A                                                                                                                                                     |
| $H_i^\lambda(\bar{h}, h')$ | a right-truncated normal distrn with variance 0 (tranquil times) and 0.20 (turbulent times), with mean at the current human capital and a lower bound of $h_{o,i}$ |
| $G_i$                      | normal distrn on $[0, .9h_{o,i}]$ with mean 0.7 and variance 0.01.                                                                                                 |

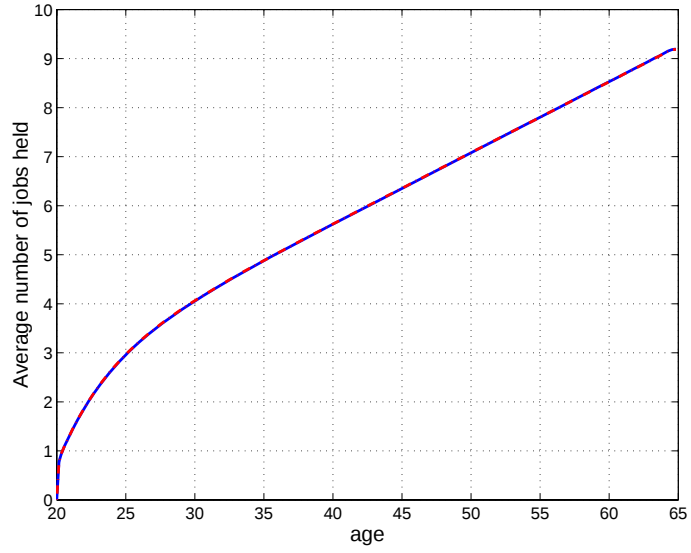


Figure 1: Workers' average number of jobs held at different ages in the U.S. in tranquil times.

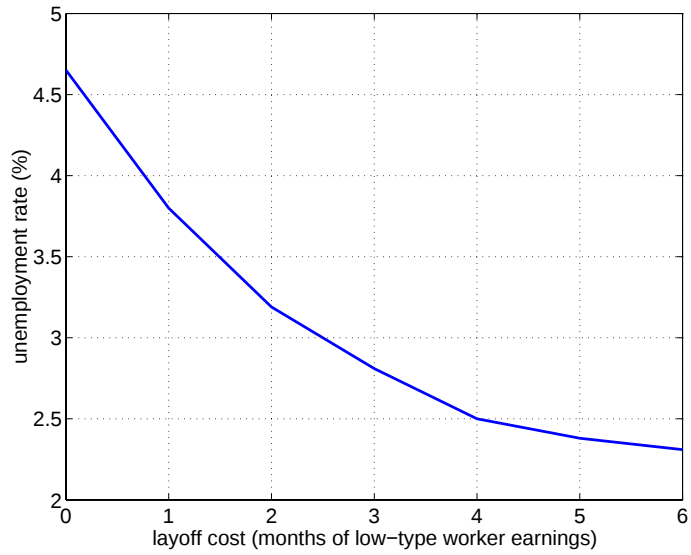


Figure 2: Unemployment rate as a function of layoff costs in Europe in tranquil times. Layoff costs are measured in terms of months of low-type worker earnings.

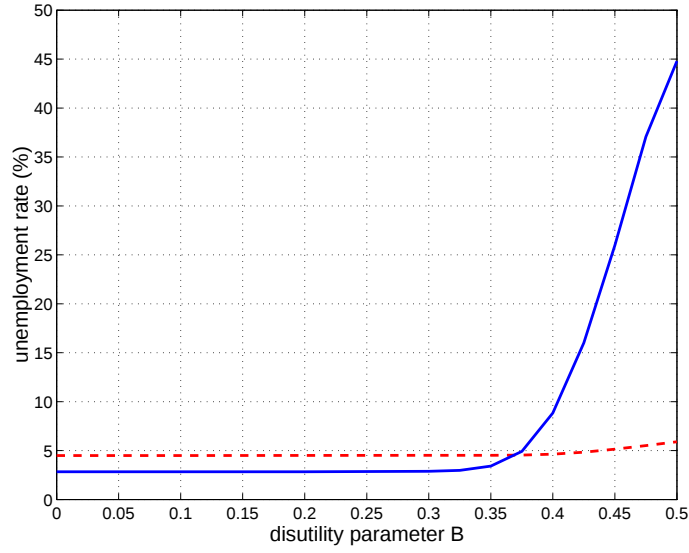


Figure 3: Unemployment rates as a function of the disutility of work  $B$ . The solid line is Europe and the dashed line is the U.S in tranquil times.

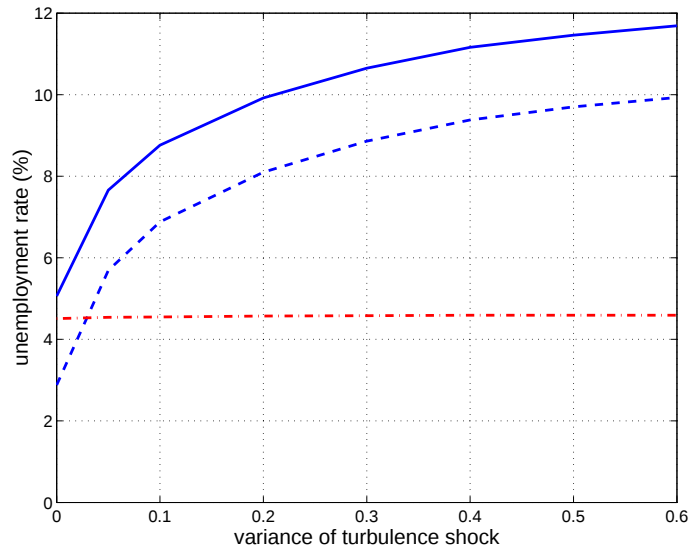


Figure 4: Unemployment rates as a function of turbulence, as measured by the variance of the right-truncated normal distribution that governs human capital losses. The solid and dashed line are Europe with a minimum wage equal to 60% of low-type worker earnings and no minimum wage, respectively. The dash-dotted line is the U.S.

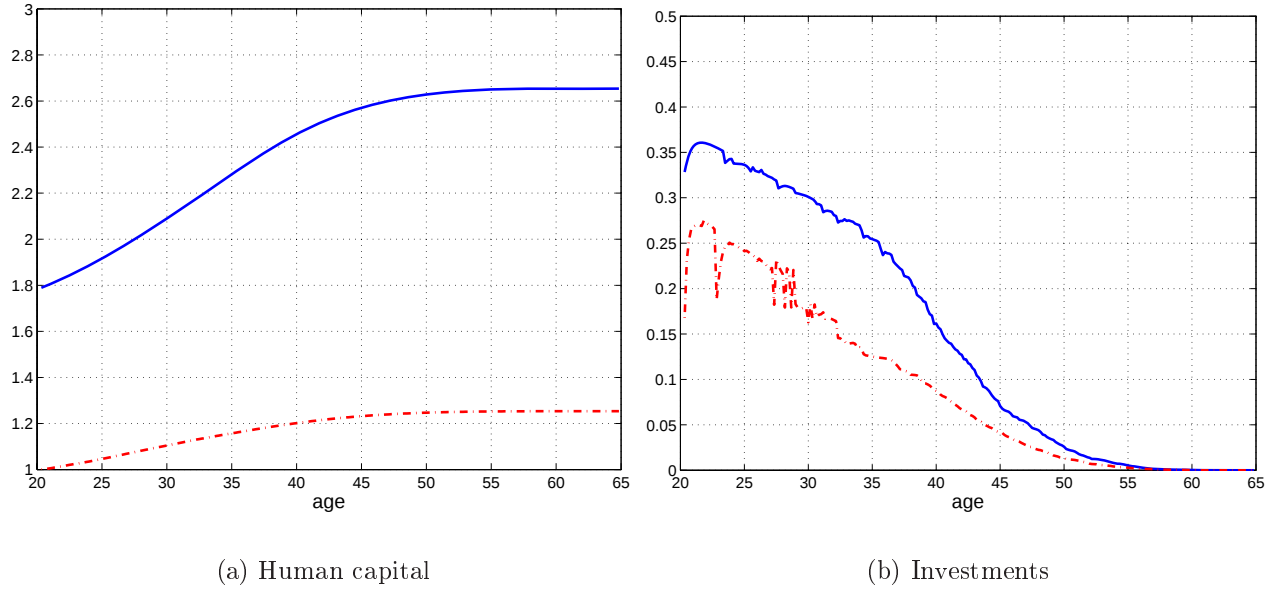


Figure 5: Human capital (panel a) and investments in human capital (panel b) as a function of age in the U.S. in tranquil times. The solid line is high-type workers and the dashed line is low-type workers.

## 7 Outcomes

## 8 Concluding remarks

In the last couple of decades, European welfare states have instituted various benefit programs specifically targeted at older workers. Our model incorporates no such age-specific programs, government labor market programs in our model being open to workers of all ages. However, our age-blind programs have their most dramatic effects on workers' behavior at the end of their careers. This outcome makes us suspect that ...

|           | Europe   |           | U.S.     |           |
|-----------|----------|-----------|----------|-----------|
|           | Tranquil | Turbulent | Tranquil | Turbulent |
| Low type  | 2.89     | 11.27     | 4.51     | 4.58      |
| High type | 2.86     | 6.78      | 4.50     | 4.55      |
| All       | 2.88     | 9.92      | 4.51     | 4.57      |

Table 7: Unemployment rates in percent. Low-type (high-type) workers constitute 70% (30%) of the population.

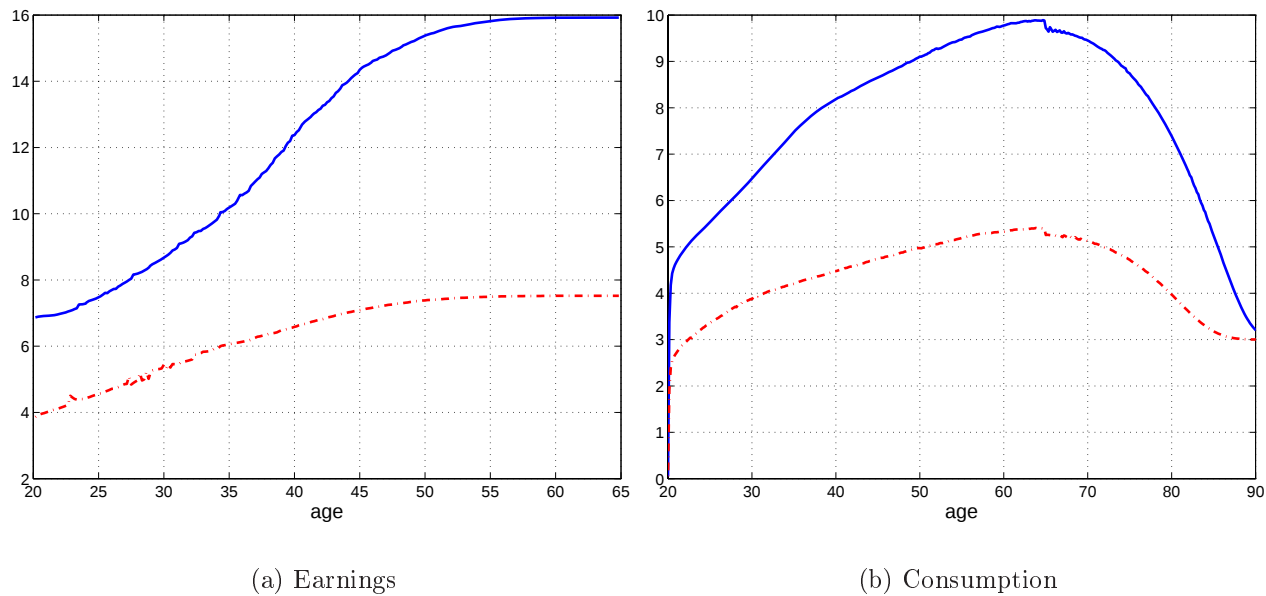


Figure 6: Earnings (panel a) and consumption (panel b) as a function of age in the U.S. in tranquil times. The solid line is high-type workers and the dashed line is low-type workers.

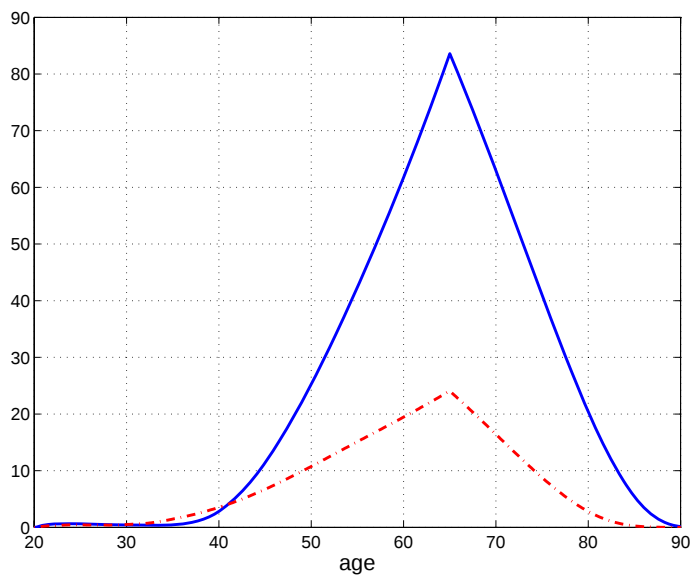


Figure 7: Assets as a function of age in the U.S. in tranquil times. The solid line is high-type workers and the dashed line is low-type workers.

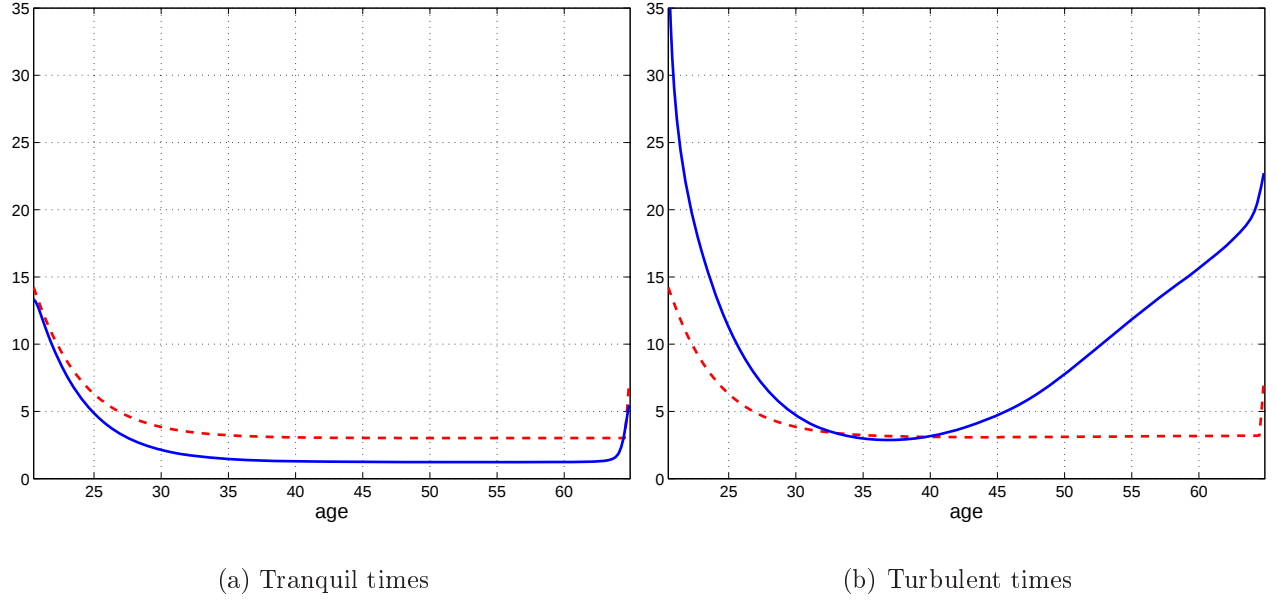


Figure 8: Unemployment rates as a function of age. The solid line is Europe and the dashed line is the U.S in tranquil times (panel a) and in turbulent times (panel b).

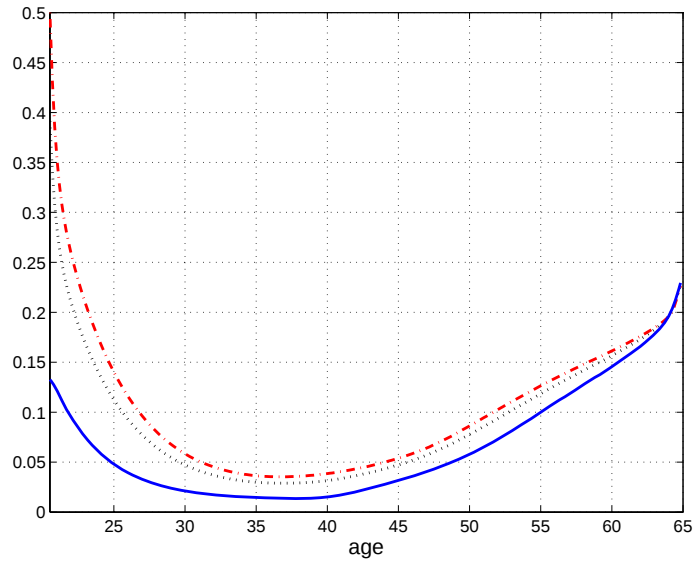


Figure 9: Unemployment rates as a function of age in Europe in turbulent times. The solid line is high-type workers, the dashed line is low-type workers, and the dotted line is all workers.

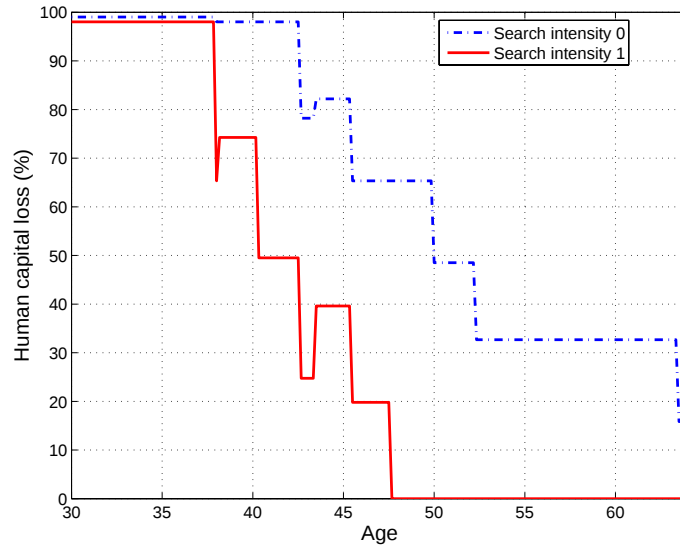


Figure 10: Optimal search intensity of the average high-type worker in Europe in tranquil times, as a function of age and ‘human capital loss’. The agent is assumed to hold the average wealth level and to be entitled to benefits based on average earnings in her age group. The search intensity is plotted for different levels of human capital below the average level in her age group, where the difference between these numbers is interpreted as her ‘human capital loss’. The solid (dashed) line is the contour curve for full (zero) search intensity.

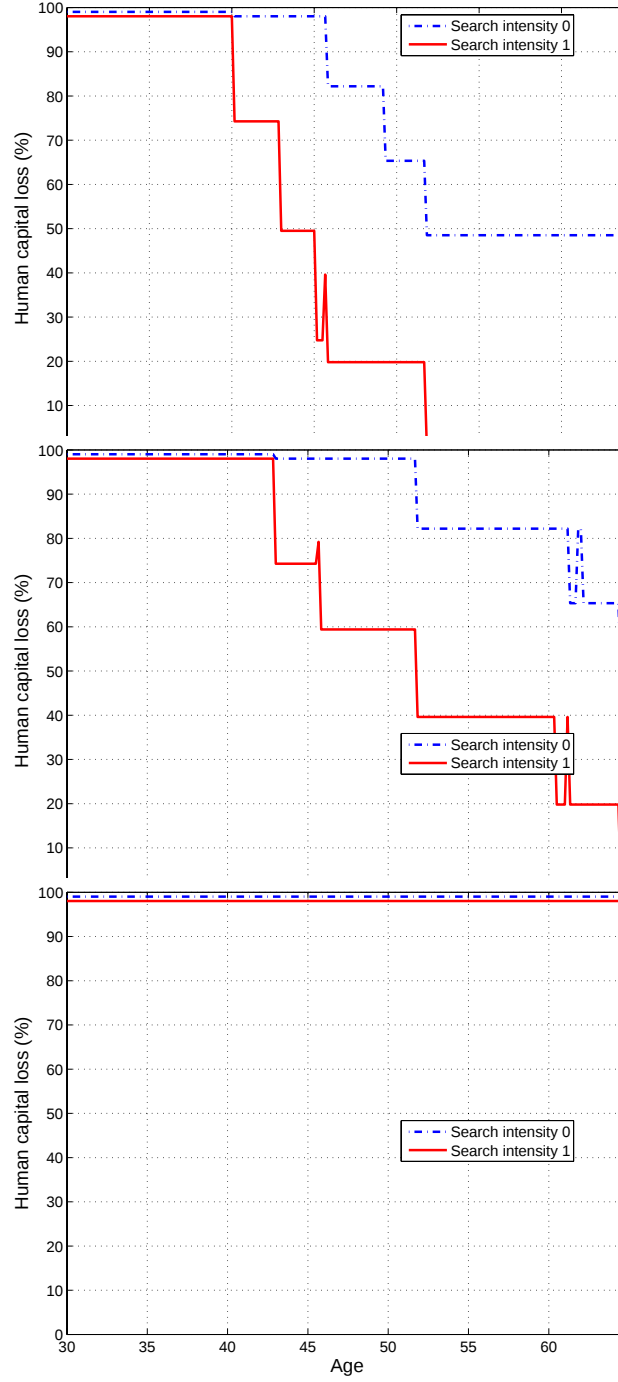


Figure 11: Optimal search intensity of the average high-type worker in the U.S. in tranquil times. Panels, from above, depict the first, second and third period of unemployment, respectively. (For a description of the worker's state vector, see the caption to figure 10.)

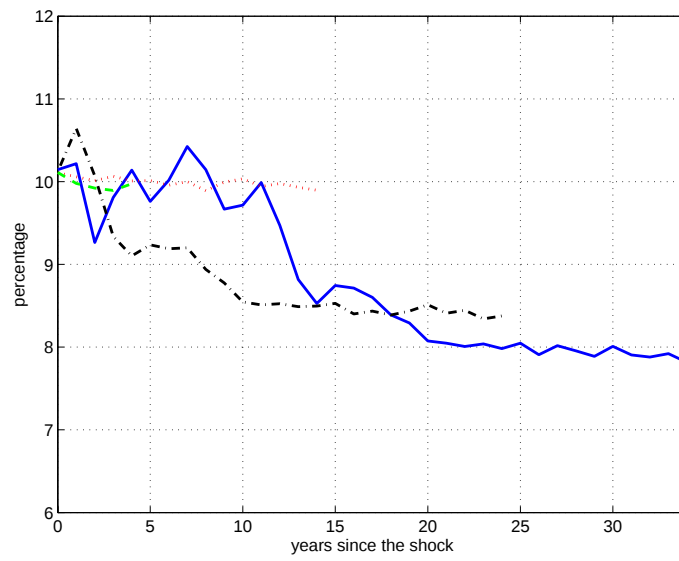


Figure 12: Earnings loss relative to the age-earnings profile for high-type workers in the U.S. in tranquil times, after a hypothetical one-time loss of human capital that causes an initial decline in income by 10%. The curves refer to representative samples of the population at age 30, 40, 50 and 60, respectively, for whom the lengths of remaining income data span 35, 25, 15 and 5 years, respectively.

...understand the pervasive microeconomic evidence on increased earnings instability, surveyed by Katz and Autor (1999), as well as other evidence pointing to a more volatile environment for workers, e.g. the substantial increase in occupational and industry mobility in the U.S. over the period 1968–1997, as documented by Kambourov and Manovskii (2008).

## A Skill acquisition technology

For a given state of human capital  $h_t$  at the beginning of a period year and a choice  $l_t$  of investment in human capital, the deterministic Ben-Porath technology  $h_{t+1} = h_t + A_i(h_t l_t)^\nu$  would tell us  $h_{t+1}$  should be at the end of the year. We have to adapt that outcome because we discretize the state space by insisting that  $h$  lie on one of the 20 grids of human capital. We design stochastic transition matrices that guarantee that the mathematical expectation of  $h_{t+1}$  is the outcome predicted by the deterministic Ben-Porath technology  $h_{t+1} = h_t + A_i(h_t l_t)^\nu$ . For example, suppose that  $h_t$  is 1.0 (grid point number 1) and that  $h_{t+1} = 1.2$  is implied by plugging a particular choice of  $l_t$  into the deterministic Ben-Porath technology; and suppose that the two nearest grid points are grid point number 1 = 1.0 and grid point 2 = 2.0. Then conditional on being at grid 1 today we would set the transition probability of going to grid point 2 tomorrow to  $q(1, 2) = 0.2$ , and similarly we would set  $q(1, 1) = 0.8$ .

To compute the transition matrix under our bi-monthly frequency, we guess and iterate. First of all, we make sure that agents do not want to travel more than one grid point over a period of one year (this is just to simplify computations). For each state, choice pair  $h_t, l_t$ , we first find the probability of staying at the current grid in the next period (in two months) is  $p$ . We can then compute recursively the expected human capital in each period up to the beginning of the next year, that is, in 6 model periods, or 12 months. We check if it coincides with what it should be according to the deterministic Ben-Porath technology, and adjust  $p$  until we achieve the right value. We search in this way for all  $h_t, l_t$  combinations to compute the entire transition matrix  $H_i^n(h_t, h_{t+1}; l_t)$ .

We shall set  $A_i = 0.05046$  (for the low type  $i$ ) and  $0.06554$  (for the high type  $i$ ) and  $\nu = 0.8$  (common for both types). We set  $h_{o,i}$ , the initial human capital when an agent becomes experienced, to be 1.0 (for the low type) and 1.778 (for the high type).

The support of  $G_i$  is  $[0, .9n(h_{o,i}, 0)]$ .

The value of parameter  $\nu$  falls in the range of estimates in the applied labor literature. We calibrated the difference in  $A_i$  and initial human capital  $h_{o,i}$  between two types so that we match the difference in earnings between two types (college graduates and non-college graduates) at ages 25 and 50.

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