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Policies on Life-Cycle Unemployment**

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The Blighted Youth: The Impact of Recessions and Policies on Life-Cycle Unemployment*

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Abstract: We construct a theoretical model of labor markets with human capital accumulation to understand and quantify the earnings losses for young workers generated by unemployment: unemployment represents time forgone in terms of human capital accumulation, which adversely affects long-term income prospects of individuals. We show that lifetime earnings losses generated by job-displacement are larger for individuals with lower capacity to accumulate human capital and during an economic downturn, as documented in the empirical literature. At the aggregate level, the framework delivers youth unemployment rates that are higher and more sensitive to fluctuations in aggregate productivity than total unemployment rates. Additionally, in economies with a higher tax-wedge, unemployment rates are more sensitive to aggregate productivity shocks. A higher tax-wedge and minimum wage increase the long-term earnings losses produced by job-displacement, especially for low-skill individuals.

Keywords: aggregate fluctuations, directed search, unemployment, worker heterogeneity, life cycle, human capital

JEL Classification: E24, E32, J63, J64

Resumen: Construimos un modelo teórico de mercados laborales con acumulación de capital humano para entender y cuantificar las pérdidas de ingresos de largo plazo de los jóvenes generadas por el desempleo: el desempleo representa tiempo perdido en términos de acumulación de capital humano, lo cual afecta negativamente las perspectivas de largo plazo. Mostramos que las pérdidas generadas por el desempleo son mayores para aquellos individuos con menor capacidad de acumular capital humano y durante una recesión. En términos de variables agregadas, las tasas de desempleo de los jóvenes son más altas y más sensibles con respecto al ciclo económico. En economías con mayor distorsión impositiva las tasas de desempleo son más sensibles al ciclo económico. Finalmente, mayores distorsiones impositivas y salarios mínimos incrementan las pérdidas de largo plazo que generan la pérdida de empleo, particularmente para aquellos individuos con menor capacidad para acumular capital humano.

Palabras Clave: ciclos económicos, modelos laborales de búsqueda, desempleo, heterogeneidad de trabajadores, ciclo de vida, capital humano

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1 Introduction

Young workers suffer large negative and long-lasting effects on earnings when entering the labor market during a downturn. The purpose of our study is to understand, by means of a theoretical model of labor markets, the potential channels through which costs generated by recessions and unemployment operate. In particular, our focus is on human capital: unemployment represents time forgone in terms of experience accumulation and the depreciation of skills, either general or specific, which adversely affects long-term income prospects of individuals.¹

To this effect we build a life-cycle heterogeneous worker model of unemployment with on-the-job human capital accumulation and aggregate productivity shocks.² We find an important role for worker heterogeneity defined in terms of differentiated capacity for human capital accumulation over the life-cycle. Huggett, Ventura and Yaron (2006, 2011) exploit life-cycle models of human capital accumulation to replicate the age dynamics and cross-sectional properties of the U.S. earnings distribution. They find that differences in the capacity to accumulate human capital are essential to reproduce the increase in earnings dispersion over the life-cycle and that they, jointly with differences in initial levels of human capital, account for the bulk of the variation in the present value of earnings across agents. This type of heterogeneity delivers an important result in our model (consistent with the empirical literature): lifetime earnings losses generated by unemployment are larger for individuals with lower capacity to accumulate human capital. Furthermore, losses generated by unemployment are larger during an economic downturn (as documented by Davis and von Wachter, 2011), as it takes longer for individuals to regain employment status.

The framework proposed delivers youth unemployment rates that are higher and more sensitive to fluctuations in aggregate productivity than total unemployment rates, a property that has been empirically documented (Bassanini and Duval, 2006). Additionally, exploiting cross-country panel data for advanced economies, we establish that in economies with a higher *tax-wedge*, unemployment rates are more sensitive to the this type of shock, behavior that is replicated by our model.³

The quantitative model builds upon the theoretical developments of Guido Menzio and Shouyong Shi (2010, 2011), which features directed job search and free entry of firms. The main advantage of this combination is the nature of the resulting *block recursive equilibrium*: value and policy functions of agents are independent of the endogenous distribution of workers across individual states (they will depend on the aggregate state of the economy only through the realization of the aggregate pro-

¹We abstract from welfare losses associated with incomplete markets for risk sharing (see Rogerson and Schindler, 2002).

²Davis and von Wachter (2011) show that standard models of search and unemployment, in the Diamond-Mortensen-Pissarides (DMP) tradition, are not able to generate earnings losses comparable to those empirically estimated. We have verified that this is also true in a version of our model without human capital accumulation.

³Prescott (2004) and Ohanian, Raffo and Rogerson (2008) argue that variations in tax rates in advanced economies can account for a significant part of the cross-country differences in employment in the context of neoclassical growth models. Alternatively, Ljungqvist and Sargent (2007) emphasize the role of differences in unemployment benefits rather than tax rates.

ductivity state). This framework is thus particularly useful due to its tractability for analyzing the effect of aggregate productivity shocks on the labor market. Menzio et al. (2012) study a life-cycle model with on-the-job human capital accumulation, search and learning frictions to decompose the life-cycle profile of wages, transition rates and productivity into the effects of age variation in work-life expectancy, human capital and match quality in a non-stochastic steady state. This framework has been extended and modified to evaluate the long-term consequences of experiencing a recession for young workers entering the job market. Guo (2014) emphasizes the role of endogenous schooling as a channel through which young workers can ameliorate the losses caused by recessions. Wee (2013) stresses that entering the job market during a recession affects early career mobility and the process of learning about the comparative advantage of young workers.

We modify the wage determination process relative to previous work exploiting a *block recursive equilibrium*. In our model the market where a worker decides to search is indexed by ability, age, human capital and the wage paid in the first period. If the match is maintained wages in every period are determined through a Nash-bargaining process. Therefore, in our framework wages are explicitly defined. This differs from the *promised utility* approach where different paths for wages are consistent with the equilibrium and additional assumptions are required to define the income of workers. This contribution allows us to analyze, for example, wage growth and inequality across individuals and over the life-cycle. Furthermore, it allows us to introduce taxes and minimum wages in a standard and straightforward manner.

A number of theories can potentially predict persistent negative effects from unemployment (as discussed in Gregg and Tominey, 2005). Theories of on-the-job search will predict that displacement from a *high quality* match implies a higher probability of return to a *low quality* position. For young workers, mobility plays an important role as it contributes to early wage growth. Theories of screening have also been considered as mechanisms that are able to generate persistent income losses from unemployment. Michaud (2012) provides a theory of information and labor markets with search and matching to account for persistent wage losses of laid-off workers, where employer uncertainty about unemployed workers' abilities can account for a significant part of the long-term wage losses following a lay-off. The approach we follow is to focus on one channel that has received considerable support as a source of life-cycle wage growth and to evaluate its consistency with different results established by empirical evidence at the individual and aggregate levels.⁴

⁴There is a sizable literature analyzing the sources of life-cycle wage growth. For a recent example, see Bagger, Fontaine, Postel-Vinay and Robin (2013), who construct and estimate an equilibrium job search model with human capital accumulation, employer heterogeneity and individual level shocks. Career wage growth is decomposed into the contributions of human capital and job search, typically considered the two main driving forces of the earnings/experience profile (see also Burdett et al., 2011). Altonji et al. (2013) estimate that human capital accounts for most of the growth of earnings over a career: job shopping, the accumulation of tenure, and the growth in general skills account for log wage increases of 0.13, 0.11 and 0.61 respectively, over the first thirty years in the labor market. Bowlus and Liu (2013) estimate a model with human capital investment and job search. Their results indicate that human capital accumulation accounts for 50 percent of life cycle earnings growth, job search accounts for 20 percent and the remaining 30 percent is

We organize the exposition in the following way: Section 2 discusses the literature on the impact of recessions on young workers and the cross country-empirical evidence in terms of unemployment rates and their response to macroeconomic shocks and the tax-wedge. We also document that unemployment rates are more sensitive to total factor productivity variations in economies with a higher tax-wedge. S.3 and S.4 describe our theoretical framework and the nature of the block recursive equilibrium. S.5 describes our functional specifications and calibration procedure, S.6 describes the main results and our quantitative analysis of the model, S.7 concludes.

2 Empirical Motivation

Unemployment spells impose a persistent *scar* upon individuals both in terms of income and posterior unemployment spells (Arumpalam, 2001; Gregg and Tominey, 2005). It has also been established that recessions are associated with relatively large increases in unemployment for the young and those with lower education or less skilled individuals (Genda et al., 2010; Bell and Blanchflower, 2011). In this section, we provide an overview of the evidence on these issues. Additionally, exploiting cross-country panel data for advanced economies (following Bassanini and Duval, 2006), we document that in economies with a higher *tax-wedge*, unemployment rates are more sensitive to aggregate productivity shocks.

2.1 The Long-Term Impact of Unemployment

Entering the labor market during a recession has a large negative and persistent impact on the labor earnings of the young.⁵ Unemployment generates a direct loss of income, but there are additional large and long lasting effects that represent costs above the immediate loss. The literature is too vast for a complete review, but a set of the main results is presented, with a focus on the evidence for advanced OECD economies.⁶ We note also that some of these studies estimate the losses suffered by individuals who had unemployment spells, while others refer to losses for those entering the labor market in a downturn.

Kahn (2010) analyzes the labor market experience of those graduating from college as a function of macroeconomic conditions in the U.S. She estimates an initial wage loss of 6-7% for a 1 percentage point increase in the unemployment rate and even 15 years after college graduation the loss is 2.5% and statistically significant.

attributed to the interaction of the two channels. In Menzio et al. (2012), the accumulation of human capital accounts for 76 percent of wage growth between the ages of 18 and 30.

⁵Youth is defined as age over the minimum school-leaving age (typically 16-18 for OECD countries) and less than 25 (Bell and Blanchflower, 2011).

⁶We abstain from comparing these estimations across countries. The wide differences in labor market institutions, educational systems, demographic environments, data availability and applied methodologies make any attempt to compare the estimates an uninteresting exercise (as already pointed out in the literature). A discussion of the econometric techniques employed is outside the scope of this paper.

Oreopoulos et al. (2012), considering those graduating from college in Canada, estimate that a rise in unemployment rates by 5 percentage points implies an initial loss in earnings of about 9 percent that halves within 5 years and finally fades to zero after 10 years. The role of heterogeneity is also emphasized: advantaged graduates (at the top of the wage distribution) suffer less as they recover within 2-4 years, while earnings of less advantaged graduates can be permanently affected. The least advantaged suffer a loss of 8 percent of cumulative earnings in their first 10 years, double those of the median graduate. The effects of a recession are strongest for young workers, relative to workers with more experience.

Table 1. The Long-Term Impact of Unemployment on Youth.

country	earn. loss	period/lag	exercise (<i>shock</i>)
Austria	6.5%	accumulated	1 p.p. unemp. rate increase
Canada	5%	accumulated	5 p.p. unemp. rate increase
Japan	5-7%	12 yrs. later	1 p.p. unemp. rate increase
U.S.	2.5%	15 yrs. later	1 p.p. unemp. rate increase
Sweden	17%	5 yrs. later	50 days youth unemployment
U.K.	10%	at age 42	6 months+ of youth unemp.
U.S.	2-3%	at age 30-31	6 months of unemp. at age 22

References: Brunner and Kuhn (2010, Austria), Oreopoulos et al. (2012, Canada), Genda et al. (2010, Japan), Nordström Skans (2011, Sweden), Gregg and Tominey (2005, U.K.), Kahn (2010, U.S.), Mroz and Savage (2006, U.S.).

Although not focusing on recessions, Kletzer and Fairlie (2003) estimate the long-term costs of job displacement for young adults: five years after a job loss the shortfall in annual earnings is 9% for men relative to what would have been expected absent the job loss. For older workers total losses largely represent immediate earnings losses whereas for young workers the loss of opportunities for rapid earnings growth is more important.⁷ They suggest that for young workers, substantial costs may be associated with job displacement in the form of missed or delayed opportunities to accumulate human capital.

Brunner and Kuhn (2010) estimate the effects of labor market conditions on wages for males entering the labor market in Austria and find that a one percentage point increase in the initial local unemployment rate is associated with an approximate shortfall in lifetime earnings of 6.5 percent (average of the accumulated wage losses within the first 20 years of labor market experience). For Japan, Genda et al. (2010) estimate that a one percentage point rise in the unemployment rate at entry reduces the likelihood of being employed by 3-4 percentage points for over 12 years.

⁷Altonji et al. (2013) find that long-term earnings losses from unemployment are dominated by wages (hours of work recover quickly).

The same event leads to earnings losses of 5-7% for over 12 years for those without college education. Moreover, a recession at the time of entry not only lowers annual earnings but also raises the likelihood of nonemployment and part-time employment for the less educated.

For the U.K., Gregg and Tominey (2005) estimate the *scar* from early unemployment to be approximately 10% at age 42 for having over 6 months of youth unemployment if individuals avoid repeated exposure to unemployment. The negative impact is approximately twice as large if the effect on repeated unemployment is taken into account. Early individual unemployment experiences significantly raise the propensity to adult unemployment (see also Gregg, 2001). The role of heterogeneity is emphasized, with lesser skilled individuals suffering more adverse consequences during their lifetime (Burgess et al., 2003). The literature in general stresses the importance of heterogeneity associated with education and ability of the young workers.⁸ Individuals securing better qualifications on leaving full-time education are less prone to youth unemployment. This suggests that education can help youths recover from early unemployment but it is not commonly undertaken. Mroz and Savage (2006) estimate using U.S. data that a six-month spell of unemployment at age 22 results in an 8 percent decrease in the wage rate at age 23 and remains 2-3% lower than it otherwise would have been at age 30-31. For Sweden, Nordström Skans (2011) estimates that 50 days of unemployment in the year following high school graduation leads to a 3 percentage points higher probability to experience a similar period of unemployment and a decrease in total annual earnings of 17% 5 years later. In Norway, Raaum and Røed (2006) find that individuals who face depressed local labor markets (6% local unemployment rate vs. 1%) when they graduate from secondary education, are subject to relatively high rates of non-employment during their whole prime-age work career.

The severity of long term income losses depend on the business cycle: Davis and von Wachter (2011) estimate that in present value terms men lose on average 1.4 years of pre-displacement earnings if displaced in mass-layoffs events that occur when the national unemployment rate is below 6 percent. This loss doubles to 2.8 years of pre-displacement earnings if the event occurs when the unemployment rate exceeds 8 percent.

2.2 Policies and Labor Markets

This subsection provides a brief overview of cross-country empirical evidence for advanced OECD economies, following the work of Bassanini and Duval (2006). The focus is on the impact of the business cycle and the *tax-wedge* on total and youth unemployment rates.⁹ We are interested in establishing several empirical regularities

⁸This is not without econometric challenges: identifying causal effects of past unemployment is a difficult task due to potential unobserved heterogeneity.

⁹Addison and Teixeira (2001) survey the literature on the labor market consequences of employment protection legislation. They conclude that the preponderance of the studies support the hypothesis that stricter employment protection rules result in lower employment-population ratios. There is, however, no consensus with respect to the effect on unemployment rates. See also Bas-

that will be exploited to validate our quantitative model.

Table 2. Unemployment Rate Equations.

	total (male)		youth (male)	
tax-wedge	0.28***	0.21***	0.45***	0.34***
union density	-0.06***	0.03	-0.11***	0.04
employment protection	-0.55*	-0.50	0.51	-0.38
high corporatism	-1.14***	-1.43***	-1.17	-1.73**
avg. replacement rate	0.14***	0.09***	0.15***	0.08*
output gap	-0.50***	—	-0.98***	—
tfp shock	—	-10.99***	—	-27.44***
terms of trade	—	18.51***	—	33.86***
interest rate	—	0.16***	—	0.26***
labor demand	—	17.60***	—	33.87***
country controls	yes	yes	yes	yes
time controls	yes	yes	yes	yes
R-squared	0.89	0.88	0.90	0.89
n. observations	405	372	404	371

Statistical significance: *** 1%, ** 5%, * 10%.
Source: Bassanini and Duval (2006), WDI.

The *tax-wedge* is defined as the difference between the gross labor costs to employers and the consumption wage paid to employers, i.e. the wage after deduction of direct and indirect taxes, including payroll taxes, income taxes and consumption taxes (Addison and Teixeira, 2001). Nickell et al. (2005) estimate that a 10 percentage point increase in total employment tax rate leads to approximately a 1 percentage point increase in unemployment in the long run. They also find that changes in labor market institutions explain approximately 55% of the rise in European unemployment from the 1960s to the first half of the 1990s, much of the remainder being due to the recession in the latter period. They estimate that changes in the benefit system and increases in labor taxes contribute the most to the increase of 6.8 percentage points in unemployment in this period: the combination of benefits and taxes are responsible for two thirds of the part of the long-term rise in European unemployment that the considered institutions explain (see also Nickell and Layard, 1999).

In line with these findings, Bassanini and Duval (2006) estimate that changes in labor market institutions can account for two-thirds of non-cyclical unemployment changes in OECD countries.¹⁰ In particular, they estimate that a 10 percentage point

sanini and Duval (2006) and Nickell et al. (2005). The ambiguous impact of firing costs is found in the theoretical literature as well (an explanation is suggested by Ljungqvist, 2002).

¹⁰The *labor demand* variable is defined as the logarithm of the labor share in business-sector GDP purged from the short-run influence of factor prices. An increase in this variable is interpreted as

reduction in the tax-wedge would be associated with a drop in the unemployment rate by 2.8 percentage points. We first re-estimate their specifications using male unemployment rates. For a 10 percent point reduction in the tax-wedge the total male unemployment rate decreases by 2.1-2.8 percentage points, the youth unemployment rate decreases by 3.4-4.5 percentage points (Table 2).¹¹ Additionally, youth unemployment rates are more sensitive to total factor productivity variations and other macroeconomic shocks (see also Bell and Blanchflower, 2011). We then divide the 20 countries in the sample into a *low tax-wedge* and a *high tax-wedge* group according to the average tax-wedge registered for each country. We find that the coefficients on total factor productivity shocks are larger (in absolute terms) for the high tax-wedge economies (Table 3).

<i>youth unemployment</i>	full sample	low wedge	high wedge
coefficient on TFP	-27.44***	-23.97***	-29.65***
<i>total unemployment</i>	full sample	low wedge	high wedge
coefficient on TFP	-10.99***	-8.84*	-13.84**

Statistical significance: *** 1%, ** 5%, * 10%.
Data Source: Bassanini and Duval (2006), WDI.

Additionally, there is a vast (although somewhat controversial) literature on the employment effects of minimum wages. Neumark and Wascher (2006) provide a comprehensive review of the work in this area and conclude that most research points to negative employment effects due to minimum wages and to stronger negative effects for the young and least-skilled groups (see also Nickell and Layard, 1999). Neumark and Nizalova (2007) find evidence that individuals in their late 20s earn less the longer they were exposed to a higher minimum wage at younger ages. They attribute part of the losses to forgone labor market experience due to the negative employment effects caused by minimum wages.

3 Baseline Environment

In this section we describe the theoretical framework without permanent heterogeneous ability to avoid cumbersome notation.¹² The framework consists of an adverse labor demand shock that raises unemployment (for further details see Bassanini and Duval, 2006).

¹¹Berger and Heylen (2011) find that, in addition to taxes, the composition of government expenditures are important in explaining variation in hours worked across countries and over time. Productive government expenditures and employment subsidies (such as child-care services) account for part of the differences within Europe.

¹²Introducing this dimension is straightforward, as it amounts to solving separately for the block

life-cycle model with on-the-job human capital accumulation. There are frictional labor markets with search and matching. Search is directed and markets are labeled by age of the worker, human capital and the first period payment to the worker. After the first period, wages are determined through a Nash-bargaining process. There are aggregate and idiosyncratic (match-specific) productivity shocks.¹³

3.1 Demographics

There is a continuum of workers of measure normalized to one, uniformly distributed across overlapping generations with age $t \in \{1, \dots, T\}$. Each worker is endowed with one indivisible unit of labor. The mass of entering (newly born) workers is equal to $1/T$, which equals the mass of retiring/dying workers. We assume risk neutrality for both workers and firms and a common discount factor $\beta \in (0, 1)$.

3.2 Production Technology and Human Capital Accumulation

There are two stochastic productivity processes in the model: aggregate productivity is denoted $y \in Y$ with an AR(1) process denoted $\Lambda(y' | y)$ and match idiosyncratic productivity $z \in Z$ with an AR(1) process denoted $\Lambda(z' | z)$. We may also write $s = (z, y)$ and $\Lambda(s' | s)$ as the joint process (this allows for more general joint stochastic processes).

The human capital of the worker is $h \in \mathbf{R}_+$, which evolves according to the law of motion $h' = h + 1$ for the periods during which the worker is employed and may deteriorate (depending on the calibration procedure) when the worker is not employed. There is an initial level of human capital \underline{h} equal to one for all newborn workers. When a match between a worker and a firm is destroyed, human capital depreciates to $\mu(h)$, with a lower bound at \underline{h} (we discuss an alternative calibration procedure below). The upper bound on human capital is \bar{h} , with $\bar{h} \leq T$. Production is carried out in a match between a firm and a worker with production technology $f(y, z, h)$.

3.3 Labor Markets

There is continuum of markets labeled by $(w, h, t, y) \in \mathbf{R}_+ \times \mathbf{N}^3$ where firms commit to pay w for the first period of the match to a worker with (h, t) . The tightness for a labor market with (w, h, t) is denoted $\theta_t(w, h, \psi)$. After the initial period, if the match is not dissolved, the wage is determined through Nash-bargaining. There is a continuum of firms with positive measure (a continuum of potential firms having infinite mass), which will satisfy a free-entry condition to close the model

recursive equilibrium for the different types of ex-ante heterogeneous workers. With that extension markets are also indexed by ability of the worker. The tax-wedge is a tax on payments to the worker (see the appendix).

¹³We consider a *two-state* environment with employment and unemployment. Rogerson and Shimer (2011) find that movements in and out of the labor force are relatively unimportant at business cycle frequencies for the United States, although they gain relevance in other OECD economies. Elsby et al. (2015), however, estimate that transitions at the participation margin account for around one-third of the cyclical variation in the unemployment rate in the U.S.

(this condition is discussed below).

The measure of unemployed workers is written as $u(h, t)$ where $u : \mathbf{N}^2 \rightarrow \mathbf{R}_+$, the measure of employed workers is $e(z, h, t)$ where $e : Z \times \mathbf{N}^2 \rightarrow \mathbf{R}_+$. The aggregate state vector is then $\psi = (u, e, y)$. For the rest of this section we assume that a *block recursive equilibrium* exists and omit ψ from the vector of state variables, the aggregate shock y does remain as a relevant aggregate state variable. The existence of the *block recursive equilibrium* is proven by construction in the appendix.

3.4 Timing

The timing within a period is as follows:

- **Entry-and-Exit of Workers, Aggregate Shock.** At the beginning of the period newly born workers enter the market and workers of age $T + 1$ retire and die. The aggregate productivity shock y is revealed.
- **Search and Matching.** The unemployed workers search for a job with probability λ_u , while employed workers are allowed to search for an alternative job with probability λ_e . A firm opens a vacancy after paying vacancy cost c_v . A worker in market (w, h, t, y) meets a vacancy with probability $p(\theta_t(w, h, y))$ where $p : \mathbf{R}_+ \rightarrow [0, 1]$ is a twice-differentiable, strictly increasing and strictly concave function with $p(0) = 0$ and $p(\infty)=1$. A vacancy in market (w, h, t, y) meets a worker with probability $q(\theta_t(w, h, y))$ where $q : \mathbf{R}_+ \rightarrow [0, 1]$ is a twice-differentiable, strictly decreasing function, with $q(\theta) = p(\theta)/\theta$, $q(0) = 1$ and $q(\infty)=0$.
- **Wage Determination.** When the worker meets a new firm, the firm pays the initial posted w in the first period. If the worker is matched with no alternative job offers, the wage is determined through Nash-bargaining with the current firm. If no agreement is reached, the match is destroyed. The unemployed worker accepts the offer he receives, otherwise produces and consumes b at home.
- **Production.** The idiosyncratic productivity state at the beginning of the period is z , at the production stage the new idiosyncratic shock z' is revealed. For new matches idiosyncratic productivity is known in advance and equal to $\bar{z}_e \in Z$ if the worker comes from a previous job, $\bar{z}_u \in Z$ if the individual was previously unemployed. The match produces $f(y, z', h)$. The accumulation of human capital takes place with production: a matched worker that enters the period and produces with human capital h , is endowed with human capital $h' = h + 1$ immediately after production takes place. The matched worker gets paid and his consumption takes place.
- **Exogenous Separation.** There is a probability δ of a shock that destroys the match, the rate of exogenous job destruction (in the calibration section we specify $\delta(h)$ as a function of human capital).

3.5 Value of the Worker: Unemployment

We now describe the value of the unemployed worker before the search stage. With probability λ_u the unemployed individual has the possibility of searching. This search will be successful with probability $p(\theta_t(w^u, h, y))$, in which case the individual receives wage w^u and enters the following period as an employed worker with probability $1 - \delta$. New matches produce with idiosyncratic productivity value $\bar{z}_u \in Z$ in their first period when the individual was previously unemployed. This will also be the state value at the beginning of the following period. With probability δ the match is destroyed for exogenous reasons.

The unemployed worker may remain unemployed with probability $(1 - \lambda_u p(\cdot))$. In this case, he produces and consumes b and enters the following period with unemployment status, with unchanged level of human capital at age $t + 1$ (below we consider alternative processes for human capital during unemployment). We can then write the beginning-of-the-period value of unemployment as:

$$U_t(h, y) = (1 - \lambda_u p(\theta_t(w^u, h, y))) \left\{ b + \beta \sum_{\{y'\}} \Lambda(y' | y) U_{t+1}(h, y') \right\} + \lambda_u p(\cdot) \left\{ w^u + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) V_{t+1}(h', \bar{z}_u, y') + \delta U_{t+1}(\mu(h'), y')) \right\}$$

where V_{t+1} is the beginning of the period value of the matched worker (after the aggregate shock is revealed). The policy function of the unemployed worker is $w_t^u(h, y)$.

3.6 Value of the Worker: Employment

A matched worker may be given a chance to search for an alternative job offer with probability λ_e , this search results in a match with probability $p(\theta_t(w^a, h, y))$. If successful he receives the posted wage of the corresponding labor market and enters the next period as a matched worker with probability $1 - \delta$. New matches produce with idiosyncratic productivity value $\bar{z}_e \in Z$ in their first period when the individual was previously employed.

With probability $(1 - \lambda_e p(\cdot))$ the worker does not receive an alternative job offer and bargains the wage with the current employer (this value is denoted by $V_t^b(h, z, y)$). The value function is then:

$$V_t(h, z, y) = (1 - \lambda_e p(\theta_t(w^a, h, y))) \left\{ V_t^b(h, z, y) \right\} + \lambda_e p(\theta_t(\cdot)) \left\{ w^a + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) V_{t+1}(h', \bar{z}_e, y') + \delta U_{t+1}(\mu(h'), y')) \right\}$$

The policy function for a matched worker is denoted $w_t^a(h, z, y)$. Before discussing how this value is determined through the bargaining process it will be useful

to describe the problem of the firm.

3.7 Value of the Firm

At the beginning of the period, when the aggregate shock is revealed, the value of a currently matched firm is $F_t(h, z, y)$. After the search stage there are two possible outcomes, with probability $\lambda_e p(\theta_t(w^a, h, y))$ the worker has found an alternative job offer and the previous match is destroyed. If the worker has no alternative job offer the new value of the firm is determined at the bargaining stage $F_t^b(h, z, y)$. We can then write the beginning-of-the-period value of the firm as:

$$F_t(h, z, y) = (1 - \lambda_e p(\theta_t(w^a, h, y))) F_t^b(h, z, y)$$

The value of a newly matched firm is $G_t(w, h, \bar{z}, y)$:

$$G_t(w, h, \bar{z}, y) = f(y, \bar{z}, h) - w + \beta (1 - \delta) \sum_{\{y'\}} \Lambda(y' | y) F_{t+1}(h', \bar{z}, y'),$$

We turn next to the bargaining stage.

3.8 Determination of Wages (Nash Bargaining)

If the worker was unsuccessful in obtaining an alternative offer, his outside option is (human capital depreciates if the match is destroyed):

$$b + \beta \sum_{\{y'\}} \Lambda(y' | y) U_{t+1}(\mu(h), y')$$

while reaching an agreement with the current employer gives (before z' is revealed):

$$w^b + \beta \sum_{\{s'\}} \Lambda(s' | s) \left\{ (1 - \delta) V_{t+1}(h', z', y') + \delta U_{t+1}(\mu(h'), y') \right\}$$

For the firm, at the bargaining stage the outside value is zero. The value of maintaining the match is:

$$F_t^b(h, z, y) = -w^b + \sum_{\{s'\}} \Lambda(s' | s) \left\{ f(y, z', h) + \beta (1 - \delta) F_{t+1}(h', z', y') \right\}$$

Note that current period production takes place with productivity value z' and y, z' is not known at the bargaining stage. There is a cutoff function $z_t^b(h, y)$, the lowest level of the idiosyncratic productivity shock such that the surplus of the worker and the firm is non-negative. Given these values, worker and firm bargain over the wage, through a Nash-bargaining process where the worker has bargaining power ξ (see Appendix) that determines $w_t^b(h, z, y)$. Finally $F_{T+1} = 0$, $U_{T+1} = 0$ and $V_{T+1} = 0$.

3.9 New Vacancies and Free Entry Condition

To close the model we specify the free entry condition of firms. The cost of a vacancy is c_v , in equilibrium the following condition has to hold:

$$c_v \geq q(\theta_t(w, h, y)) \left\{ f(y, \bar{z}, h) - w + \beta(1 - \delta) \sum_{\{y'\}} \Lambda(y' | y) F_{t+1}(h', \bar{z}, y') \right\}$$

where \bar{z} depends on whether it is a market for employed or unemployed individuals, and $\theta_t(w, h, y) \geq 0$ holds with complementary slackness.

4 Block Recursive Equilibrium

Definition. A *Block Recursive Equilibrium* (BRE) consists of value functions U_t for unemployed workers, V_t for employed workers, F_t for previously matched firms and G_t for newly matched firms, policy functions w_t^u for unemployed workers and w_t^a for employed workers, a bargained wage function w_t^b , a cutoff productivity function z_t^b , and a tightness function θ_t for $t = 1, \dots, T$ such that (i) $U_t, V_t, F_t, G_t, w_t^u, w_t^a, w_t^b, z_t^b$ and θ_t depend on ψ only through y for $t = 1, \dots, T$, (ii) F_t, G_t and θ_t are consistent with the firm's rationality and the free-entry condition for $t = 1, \dots, T$, (iii) U_t and w_t^u solve the unemployed worker's problem for $t = 1, \dots, T$, (iv) V_t and w_t^a solve the employed worker's problem for $t = 1, \dots, T$, and (v) w_t^b and z_t^b solve the bargaining problem between an employed worker and a firm for $t = 1, \dots, T$.

Theorem. A recursive equilibrium exists and is block recursive and unique (see Appendix for proof).

To gain some intuition on this result first consider the assumption of directed search. Markets are indexed by age and human capital of the worker (and ability when this extension is considered). Thus, a firm opening a vacancy in a particular market will know the characteristics of the worker that it will potentially find. If search was not directed, to calculate the expected discounted profits of opening a vacancy the firm would need to know the distribution of workers with different characteristics (for example, human capital determines in part the productivity of the match).

In the market that the workers searches for a job, the number of vacancies will adjust so that the free-entry condition holds for the firms. There are different pairs of first-period wages and market tightness that could deliver zero expected discounted profits for firms. The additional condition that determines this pair in equilibrium is a concave maximization search problem for each particular type of worker. In the last period of the worker, it is straightforward to verify that all value and policy functions as well as bargained wages are independent of the distribution of workers over their individual state variables. By backward induction a *block recursive equilibrium* is constructed.

5 Parameters and Function Specifications

In this section we describe the specification of the different functions of the model, the calibration procedure and the standard parameters taken from the literature.

5.1 Function Specifications and Predetermined Parameters

The production function for a match is as follows:

$$f(a, y, z, h) = e^{z+y} h^{\gamma_a}$$

where z is the match-idiosyncratic productivity shock, y is the aggregate productivity shock, γ_a determines curvature with respect to human capital h and varies with the type of worker.

A time period is one month and $\beta \in [0.996, 0.9967]$ is typically set so that the annual real interest rate is in the range of 4-5 percent. Bargaining power, determined by ξ , is equal for firms and workers which is standard in the literature. We consider a working life of 40 years and the range of human capital is from $\underline{h} = 1$ to \bar{h} , with $\bar{h} = T$.

The autocorrelation and standard deviation of the aggregate productivity process are set to match (at an aggregated quarterly frequency) the autocorrelation and standard deviation of 0.883 and 0.02 respectively, of the detrended series of real output per worker in the non-farm business sector for the U.S., following Shimer (2005).¹⁴ The idiosyncratic productivity process follows an AR(1) process as well; as in Bils et al. (2011) we set a persistence parameter for idiosyncratic productivity of 0.97 and a standard deviation of 0.13.

¹⁴For comparison, Bils et al. (2011) set an autocorrelation parameter of 0.95 and standard deviation 0.0077. We apply the Rouwenhorst method for approximating a stationary AR(1) process following Kopecky and Suen (2010).

<i>description of parameter</i>	symbol	value
discount factor	β	0.996
periods of life	T	$40 \cdot 12$
human capital upper bound	\bar{h}	$40 \cdot 12$
aggregate process autocorrelation	ρ_y	0.924
aggregate process volatility	σ_y	0.007
idiosyncratic process autocorrelation	ρ_z	0.970
idiosyncratic process volatility	σ_z	0.130
bargaining parameter	ξ	1/2
vacancy cost	c_v	$10.42 \cdot b$
matching function	$p(\theta)$	$\theta^{1/2}$
initial idiosync. productivity unemployed	\bar{z}_u	1.000

The vacancy cost is set so that its value relative to home production is 10.42 as in Menzio, Telyukova and Visschers (2012).¹⁵ The matching function follows a standard specification. Finally, previously unemployed workers start a new match at the unconditional mean of the idiosyncratic productivity process.

5.2 Baseline Calibration

The set of calibrated parameters are enumerated in Table 5: λ_e influences the rate of transition to new jobs and λ_u governs the rate of transition from unemployment to employment (note that transition rates are endogenous in the model). The home production parameter is b and \bar{z}_e is the initial productivity for an employed worker that transitions to a new job.

<i>description of parameter</i>	symbol	value
on-the-job search probability	λ_e	0.0225
unemployed search probability	λ_u	0.850
home production	b	0.680
exogenous destruction	$\delta(h)$	see text
curvature w.r.t. human capital	$\bar{\gamma}_a$	0.0550
deviations curvature by ability level	ε_γ	0.1750
initial idiosync. productivity job-to-job	\bar{z}_e	1.707

The model incorporates exogenous job destruction and the possibility of endogenous job destruction. We want to match the life-cycle profile of the total exit

¹⁵We find that results improve with this value (compared to lower vacancy costs) in terms of how youth unemployment rates react to the tax-wedge.

rate from employment, we specify a function $\delta(h) = -0.015 \ln(h) + 0.075$, restricting $\delta(h) \in [0.00, 0.04]$. This function determines the rate of exogenous job destruction depending on the level of human capital h . Finally, γ_a takes on three values equal to $\bar{\gamma}_a$ and $\bar{\gamma}_a \pm \varepsilon_\gamma$ (restricted to be non-negative). The weights are pre-set at $\{0.25, 0.50, 0.25\}$, for the lowest to highest values respectively.

Table 6. Calibration of Parameters: Statistics.		
<i>target statistics</i>	data	model
total unemployment rate	0.056	0.056
unemp.-emp. transition rate age 40-45	0.279	0.316
emp.-emp. (new employer) transition rate	0.018	0.017
emp.-unemp. transition rate age 40-45	0.012	0.012
emp.-unemp. transition rate age 20-25	0.032	0.032
emp.-unemp. transition rate age 20	0.040	0.040
age 25: 80th-20th perc. log earnings	0.745	0.752
age 40: 80th-20th perc. log earnings	1.068	0.977
50th perc. log earnings: age 41-age 25	0.252	0.282
<i>additional statistics</i>	data	model
emp.-unemp. transition rate age 30-35	0.015	0.016
unemp.-emp. transition rate age 20-25	0.302	0.264
unemployment rate age 20-25	0.110	0.120
total emp.-unemp. transition rate: Shimer (2012)	0.020	0.016
total unemp.-emp. transition rate: Shimer (2012)	0.313	0.277

The target statistics are enumerated in Table 6: unemployment rates are averages for males for the period 1970-2015, for age 20 and over (Bureau of Labor Statistics, Current Population Survey). The transition rates by age are from Choi, Janiak and Villena-Roldán (2014), the total employment-to-employment (new employer) transition rate is from Menzio et al. (2012), earnings statistics are from Huggett et al. (2006). The total transition rates are from Shimer (2012), these are not targeted moments but we replicate them for comparison.¹⁶

5.3 Human Capital Evolution During Unemployment

As reviewed in a previous section, many studies have documented a sharp drop in wages following job-displacement and a gradual convergence afterwards (relative to a situation without job displacement). Mroz and Savage (2006) develop a theoretical model of human capital investment and their model simulations indicate that on average a six-month spell of unemployment experienced at age 22 would result in

¹⁶This data was constructed by Robert Shimer. For additional details, please see Shimer (2012).

an 8 percent lower wage rate at age 23 and 2-3 percent lower wages at ages 30-31.¹⁷ To match these two moments, we calibrate $\mu(h)$ in terms of human capital depreciation upon job-displacement.¹⁸ Additionally, in principle, we allow for human capital accumulation during unemployment.

We find that setting $\mu(h)$ equivalent to 8 periods of human capital accumulation generates a loss in wages due to job-displacement and six months of unemployment at age 22 equal to 7.2 percent at age 23, and equal to 1.6 percent at age 31.¹⁹ Under this parameterization, human capital does not deteriorate or increase during unemployment. Two observations are worth mentioning. First, the lower wages after job displacement are due to the one-time depreciation in human capital in addition to 6 months of forgone human capital accumulation. Second, to match the two moments our model requires that human capital remain fixed during unemployment. In other words, there is little room for human capital accumulation during unemployment in our model to match the two aforementioned statistics for the mid-ability individuals.²⁰

6 Quantitative Analysis

In this section we present our main quantitative results. We document how the tax-wedge affects unemployment rates and how it increases the sensitivity of unemployment rates with respect to fluctuations in aggregate productivity, we compare these results with those obtained with cross-country panel data. We compute the impact of the tax-wedge and minimum wages on job finding and job destruction rates, unemployment duration and on-the-job human capital accumulation. Finally, we evaluate how the tax-wedge and the minimum wage affect the expected long-term discounted losses generated by job-displacement in different states of the economy and for individuals with different capacity to accumulate human capital.

¹⁷In Mroz and Savage (2006) convergence is due to the positive effect on the training of young workers when they regain employment. We find in our model that this mechanism is not necessary to approximate the estimations we target.

¹⁸This depreciation may be due to firm-specific, industry-specific or occupation-specific human capital. See Sanders and Taber (2012) for a summary of the empirical literature on the different types of specificity of human capital, from which we abstract.

¹⁹In our model we perform these computations for the Nash-bargained wage of the mid-ability individual, at the middle levels of idiosyncratic and aggregate productivity shocks

²⁰Alternatively, we have analyzed a version of our model with continuous human capital depreciation during unemployment (under a conservative approach human capital depreciates at the same rate during unemployment as it accumulates during employment), following Ljungqvist and Sargent (2008) and Pavoni and Violante (2007). We find that this parameterization performs significantly worse in terms of how much unemployment rates increase with the tax-wedge and also fails to capture the sharp drop in wages following job-displacement. However, as in our baseline model, losses generated by job displacement are higher for lower skilled individuals, during recessions and with a higher tax-wedge.

6.1 Business Cycle Simulations

We simulate our model economy under different levels of the tax-wedge,²¹ and find that unemployment rates are more sensitive to aggregate productivity shocks under higher levels of the tax-wedge (Table 7).²² We can interpret these findings in light of the insights in Ljungqvist and Sargent (2014): they show that a re-configuration of a matching model that reduces the surplus of a match will increase the response of unemployment with respect to aggregate productivity shocks.²³ In our model, increasing the tax-wedge reduces this surplus. Additionally, youth unemployment rates are more sensitive to fluctuations in aggregate productivity than total unemployment rates.

Table 7. Business Cycle Moments (Model Simulations): Unemployment on TFP Regressions.			
<i>regression: TFP coefficients</i>	$\tau = 0.344$	$\tau = 0.394$	$\tau = 0.444$
youth unemployment	-12.41	-14.64	-21.20
total unemployment	-6.45	-7.73	-11.84
<i>regression: constants</i>	$\tau = 0.344$	$\tau = 0.394$	$\tau = 0.444$
youth unemployment	11.97	13.86	16.44
total unemployment	5.58	6.43	7.84

We also evaluate how average unemployment rates react to different levels of the tax-wedge (see Table 8). These changes in unemployment rates are due to reductions in job-finding rates, while job-destruction rates exhibit negligible modifications (see Table 9).²⁴

²¹The tax-wedge is defined by the OECD as the combined central and sub-central government income tax plus employee and employer social security contribution taxes, as a percentage of labour costs defined as gross wage earnings plus employer social security contributions. For the U.S. the total tax-wedge is 34.4%.

²²We simulate our model at the monthly frequency and estimate our regressions with annual averages for comparison with the evidence using cross-country panel data.

²³The intuition is that a particular magnitude of a change in productivity generates a larger change in the total surplus when the fundamental surplus is small. In the standard DMP framework, for example, the fundamental surplus is given by what remains when we deduce the value of home production (or leisure) for the worker from productivity. This surplus determines the incentives of firms to create vacancies and therefore job-finding rates.

²⁴The tax-wedge reduces the total surplus of a match and, as a result, firms require a higher vacancy filling rate to break even in equilibrium. Minimum wages, as we discuss below, do affect job destruction rates.

<i>avg. unemployment (model)</i>	$\tau = 0.344$	$\tau = 0.394$	$\tau = 0.444$
youth unemployment	0.119	0.138	0.165
total unemployment	0.056	0.064	0.079
youth/total unemployment	2.144	2.150	2.099
Δ youth unemp./ Δ tax-wedge: model	–	0.38	0.46
Δ youth unemp./ Δ tax-wedge: data*	–	0.34	0.34
Δ total unemp./ Δ tax-wedge: model	–	0.16	0.23
Δ total unemp./ Δ tax-wedge: data*	–	0.21	0.21

*From coefficients of the tax-wedge, regressions in Table 2.

We then compute the average unemployment duration for a 24 year old worker during a recession and document how it increases with the tax-wedge. As already discussed, a higher tax-wedge reduces the job-finding rates in the economy for all individuals characteristics. Additionally, as workers spend more time unemployed, the average level of human capital is reduced.

<i>youth transition rates</i>	$\tau = 0.344$	$\tau = 0.394$	$\tau = 0.444$
avg. job finding rate	0.265	0.234	0.193
avg. job destruction rate	0.033	0.034	0.034
<i>unemployment duration*</i>	$\tau = 0.344$	$\tau = 0.394$	$\tau = 0.444$
average duration (months)	4.50	5.00	6.90
std. dev. duration	4.26	5.07	7.61
average human capital	23.30	20.44	18.02

*For a 24 year-old worker unemployed during a downturn.

6.2 The Impact of Minimum Wages

A minimum wage \underline{w} sets a constraint on the Nash-bargaining solution. Mechanically, for each state we first determine the Nash-wage. If the constraint set by the minimum wage is binding then the match is destroyed unless the surplus for both firm and worker is positive. In the latter case, the share of the surplus for the worker may be higher than it would be given the unconstrained Nash-wage. The minimum wage affects job destruction but also job creation as it reduces the value of the firm of creating a vacancy given that the match will be destroyed in some states where the minimum wage is binding. Due to its potential impact on unemployment minimum wages can affect the ability of workers to accumulate human capital

and can thus have an additional impact on unemployment rates for all ages (lower human capital implies lower surplus for a match and reduced job creation by firms).²⁵

<i>avg. unemployment</i>	$\underline{w} = 0$	$\underline{w} = 5^*$	$\underline{w} = 10^*$
youth unemployment	0.119	0.145	0.170
total unemployment	0.056	0.061	0.070
youth/total unemployment	2.144	2.361	2.420
<i>youth transition rates</i>	$\underline{w} = 0$	$\underline{w} = 5^*$	$\underline{w} = 10^*$
avg. job finding rate	0.265	0.260	0.217
avg. job destruction rate	0.033	0.041	0.041
<i>unemployment duration**</i>	$\underline{w} = 0$	$\underline{w} = 5^*$	$\underline{w} = 10^*$
average duration (months)	4.50	4.51	6.45
std. dev. duration	4.26	4.16	7.07
average human capital	23.30	19.52	17.38

*Minimum wage in terms of percentiles of baseline model.
**For a 24 year-old worker unemployed during a downturn.

For the quantitative analysis, we start from the baseline economy and take the 5th and 10th percentiles of the wages in the simulated economy. We then set the minimum wage equal to these values with the rest of the parameters unchanged. As expected, the minimum wage affects job destruction rates as well as job creation and the possibilities for workers of accumulating human capital.

6.3 Losses due to Unemployment

We now compute the expected present discounted losses in labor earnings caused by job separation. The tables below shows the ratio of the expected present discounted value of labor earnings of an employed worker of age 25, relative to the expected present discounted value of labor earnings for an individual of the same age and innate ability that lost his job.²⁶ The first table shows this ratio for two different states of aggregate productivity, two different skill levels and two different tax levels, the second table performs the same computations with the introduction of the minimum wage.

²⁵The way we introduce minimum wages is similar to Gorry (2013), where a labor search model is used to analyze the impact of the Fair Minimum Wage Act in the United States, as well as to help explain the high rates of youth unemployment in France relative to the U.S. Additionally, in our model the minimum wage is a constraint on the initial wage in the market where the worker searches for a job, this also affects job finding rates.

²⁶See the appendix for a mathematical derivation of the expected present discounted value of labor earnings.

Table 11. Present Discounted Losses Generated by Job Loss: Tax-Wedge.				
	high ability: $\bar{\gamma}_a + \varepsilon_\gamma$		low ability: $\bar{\gamma}_a - \varepsilon_\gamma$	
	$\tau = 0.344$	$\tau = 0.444$	$\tau = 0.344$	$\tau = 0.444$
low aggregate productivity	1.0118	1.0120	1.0272	1.0434
high aggregate productivity	1.0117	1.0119	1.0262	1.0402

The main results are that losses are bigger: in worse aggregate states of the economy (consistent with the results in Davis and von Wachter, 2011), for lower ability individuals (as established by the empirical literature in general), in the economy with the higher tax-wedge. These results are intuitive as, for example, the tax-wedge reduces job finding rates therefore increasing the losses generated by job displacement. We also observe that higher skilled individuals are unaffected by the minimum wage levels we consider as these are not binding for them given their relatively high productivity (Table 12).

Table 12. Present Discounted Losses Generated by Job Loss: Min. Wage.				
	high ability: $\bar{\gamma}_a + \varepsilon_\gamma$		low ability: $\bar{\gamma}_a - \varepsilon_\gamma$	
	$\underline{w} = 0$	$\underline{w} = 10^*$	$\underline{w} = 0$	$\underline{w} = 10^*$
low aggregate productivity	1.0118	1.0118	1.0272	1.0392
high aggregate productivity	1.0117	1.0117	1.0262	1.0315

*Min. wage in terms of percentiles of the baseline calibration.

7 Conclusion

We have proposed a theoretical framework of labor markets to understand the mechanisms behind the losses generated by unemployment. We focused on a human capital channel: unemployment represents time forgone in terms of experience accumulation, which adversely affects long-term income prospects of individuals.

We have shown that the model delivers results that are consistent with key findings of the empirical literature at the microeconomic level as well as in terms of the behavior of aggregate variables along several important dimensions. We document how the tax-wedge affects unemployment rates and how they increase their sensitivity with respect to fluctuations in aggregate productivity, comparing these results with those obtained with cross-country panel data. We compute the impact of the tax-wedge and minimum wages on job finding and job destruction rates, unemployment duration and human capital accumulation.

Finally, we evaluate in our model how the tax-wedge and the minimum wage affect the expected long-term discounted losses generated by job-displacement in different states of the economy and for individuals with different capacity to accumulate human capital. We show that lifetime earnings losses generated by unemployment are larger for individuals with lower capacity to accumulate human capital. Furthermore, losses generated by unemployment are larger during an economic downturn (as documented by Davis and von Wachter, 2011), as it takes longer for individuals to regain employment status. It was also shown how the tax-wedge and minimum wages interact with the business cycle and have particularly adverse consequences for young and less skilled individuals.

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A Block Recursive Equilibrium

This appendix proves the existence and uniqueness of the *Block Recursive Equilibrium* in our model. To reduce cumbersome notation we proceed for an economy without human capital depreciation or heterogeneity in terms of human capital accumulation, a unique level of idiosyncratic productivity for all new matches and a constant rate of exogenous job destruction (these extensions are straightforward).

Definition. A *Block Recursive Equilibrium* (BRE) consists of value functions U_t for unemployed workers, V_t for employed workers, F_t for previously matched firms and G_t for newly matched firms, policy functions w_t^u for unemployed workers and w_t^a for employed workers, a bargained wage function w_t^b determined between an employed worker and a firm, a cutoff productivity function z_t^b , and a tightness function θ_t for $t = 1, \dots, T$ such that (i) $U_t, V_t, F_t, G_t, w_t^u, w_t^a, w_t^b, z_t^b$ and θ_t depend on ψ only through y for $t = 1, \dots, T$, (ii) F_t, G_t and θ_t are consistent with the firm's rationality and the free-entry condition for $t = 1, \dots, T$, (iii) U_t and w_t^u solve the unemployed worker's problem for $t = 1, \dots, T$, (iv) V_t and w_t^a solve the employed worker's problem for $t = 1, \dots, T$, and (v) w_t^b and z_t^b solve the bargaining problem between an employed worker and a firm for $t = 1, \dots, T$.

Theorem. A recursive equilibrium exists and is block recursive and unique.

Proof. We construct a block recursive equilibrium. Denote a statement “ $U_t, V_t, F_t, G_t, w_t^u, w_t^a, w_t^b, z_t^b$ and θ_t are uniquely computed and they depend on ψ only through y for t ” as (S_t) . We first show that (S_T) holds and then proceed by backward induction.

At age T the value of an unemployed worker with no job offer after the search stage is:

$$U_T^n(h, \psi) = b,$$

and we can write as $U_T^n(h, \psi) = U_T^n(h, y)$.

At the bargaining stage, if an agreement can be reached (the surplus of worker and firm are non-negative), the value of remaining in the current match for a worker without an alternative job offer is given by the bargained wage function:

$$(1 - \tau) w_T^b(h, z, \psi),$$

while the outside option at this stage is $U_T^n(h, y)$, and the value of the firm (recalling that $F_{T+1} = 0$) is:

$$-w_T^b(h, z, \psi) + \sum_{\{z'\}} \Lambda(z' | z) f(y, z', h),$$

and the outside value of the firm is zero.

Thus, at age T , the bargaining problem for the continuing match is:

$$\max_{\{w^b\}} \left\{ w^b (1 - \tau) - b \right\}^\xi \left\{ -w^b + \sum_{\{z'\}} \Lambda(z' | z) f(y, z', h) \right\}^{1-\xi},$$

the joint surplus is:

$$-b + \sum_{\{z'\}} \Lambda(z' | z) f(y, z', h) - \tau w^b.$$

Let the cutoff productivity $z_T^b(h, \psi)$ be the lowest z such that the surplus of both firm and worker are non-negative. Noting that y is the only necessary component in ψ to determine this cutoff, $z_T^b(h, \psi) = z_T^b(h, y)$.

If $z \geq z_T^b(h, y)$, the bargaining problem has a unique solution:

$$w_T^b(h, z, \psi) = (1 - \xi) (1 - \tau)^{-1} b + \xi \sum_{\{z'\}} \Lambda(z' | z) f(y, z', h),$$

otherwise the bargaining fails and the employed worker and the firm receive the outside value. We can see that $w_T^b(h, z, \psi) = w_T^b(h, z, y)$.

Therefore, at the bargaining stage the employed worker's value is:

$$V_T^b(h, z, \psi) = \begin{cases} w_T^b(h, z, y) (1 - \tau) & \text{if } z \geq z_T^b(h, y), \\ b & \text{if } z < z_T^b(h, y), \end{cases}$$

and the firm's value is:

$$F_T^b(h, z, \psi) = \begin{cases} -w_T^b(h, z, y) + \sum_{\{z'\}} \Lambda(z' | z) f(y, z', h) & \text{if } z \geq z_T^b(h, y), \\ 0 & \text{if } z < z_T^b(h, y). \end{cases}$$

Noting that the right hand sides of the values do not have ψ except y , we can write $V_T^b(h, z, \psi) = V_T^b(h, z, y)$ and $F_T^b(h, z, \psi) = F_T^b(h, z, y)$.

On the other hand, the value of the worker that has found an alternative job offer is simply the wage posted in the market where he has searched:

$$V_T^a(w^a, h, \bar{z}, \psi) = w^a (1 - \tau),$$

and this does not depend on ψ directly, so $V_T^a(w^a, h, \bar{z}, \psi) = V_T^a(w^a, h, \bar{z}, y)$. The value of the newly matched firm is:

$$G_T(w^a, h, \bar{z}, \psi) = f(y, \bar{z}, h) - w^a,$$

and hence $G_T(w^a, h, \bar{z}, \psi) = G_T(w^a, h, \bar{z}, y)$.

Then, the free-entry condition for the firm at this stage is (for a wage w),

$$c_v \geq q(\theta_T(w, h, \psi)) G_T(w, h, \bar{z}, y)$$

and $\theta_T(w, h, \psi) \geq 0$ with complementary slackness. It follows that:

$$\theta_T(w, h, \psi) = \begin{cases} q^{-1} \left(\frac{c_v}{f(y, \bar{z}, h) - w} \right) & \text{if } c_v \leq f(y, \bar{z}, h) - w, \\ 0 & \text{if } c_v > f(y, \bar{z}, h) - w, \end{cases}$$

and hence $\theta_T(w, h, \psi) = \theta_T(w, h, y)$ as the right hand side depends on ψ only through y . Equivalently,

$$\begin{aligned} w &= f(y, \bar{z}, h) - \frac{c_v}{q(\theta_T(w, h, y))} & \text{if } c_v \leq f(y, \bar{z}, h) - w, \\ \theta_T(w, h, y) &= 0 & \text{if } c_v > f(y, \bar{z}, h) - w. \end{aligned}$$

Thus, before the search stage the value of the matched worker is:

$$\begin{aligned} V_T(h, z, \psi) &= \max_{\{w^a\}} \left\{ \lambda_e p(\theta_T(w^a, h, y)) w^a (1 - \tau) + (1 - \lambda_e p(\theta_T(w^a, h, y))) V_T^b(h, z, y) \right\}, \\ &= \max_{\{w^a\}} \left\{ \lambda_e (-c_v \theta_T(\cdot) (1 - \tau) + p(\theta_T(\cdot)) (f(y, \bar{z}, h) (1 - \tau) - V_T^b(h, z, y))) + V_T^b(h, z, y) \right\}, \\ &= \max_{\theta \geq 0} \left\{ \lambda_e (-c_v \theta (1 - \tau) + p(\theta) (f(y, \bar{z}, h) (1 - \tau) - V_T^b(h, z, y))) + V_T^b(h, z, y) \right\}, \end{aligned}$$

so if $f(y, \bar{z}, h) \leq V_T^b(h, z, y)$ then the solution is zero, otherwise the objective function is strictly concave in θ . Thus, this problem has a unique solution $\theta_T^a(h, z, \psi)$. Since the objective function depends on ψ only through y , $\theta_T^a(h, z, \psi) = \theta_T^a(h, z, y)$ and $V_T(h, z, \psi) = V_T(h, z, y)$. Therefore,

$$\begin{aligned} w_T^a(h, z, \psi) &= f(y, \bar{z}, h) - \frac{c_v}{q(\theta_T^a(h, z, y))} & \text{if } \theta_T^a(h, z, y) > 0, \\ w_T^a(h, z, \psi) &\geq f(y, \bar{z}, h) - c_v & \text{if } \theta_T^a(h, z, y) = 0. \end{aligned}$$

Noting the market with $\theta = 0$ is empty, without loss of generality:

$$w_T^a(h, z, \psi) = f(y, \bar{z}, h) - \frac{c_v}{q(\theta_T^a(h, z, y))},$$

and hence $w_T^a(h, z, \psi) = w_T^a(h, z, y)$.

Similarly we have at the beginning of age T value of unemployment:

$$\begin{aligned} U_T(h, \psi) &= \max_{\{w^u\}} \left\{ \lambda_u p(\theta_T(w^u, h, y)) w^u (1 - \tau) + (1 - \lambda_u p(\theta_T(w^u, h, y))) U_T^n(h, y) \right\}, \\ &= \max_{\{w^u\}} \left\{ \lambda_u (-c_v \theta_T(\cdot) (1 - \tau) + p(\theta_T(\cdot)) (f(y, \bar{z}, h) (1 - \tau) - U_T^n(h, y))) + U_T^n(h, y) \right\}, \\ &= \max_{\theta \geq 0} \left\{ \lambda_u (-c_v \theta (1 - \tau) + p(\theta) (f(y, \bar{z}, h) (1 - \tau) - U_T^n(h, y))) + U_T^n(h, y) \right\}, \end{aligned}$$

so if $f(y, \bar{z}, h) \leq U_T^n(h, y)$ then the solution is zero, and otherwise the objective function is strictly concave in θ . Thus, this problem has a unique solution $\theta_T^u(h, \psi)$. Since the objective function depends on ψ only through y , $\theta_T^u(h, \psi) = \theta_T^u(h, y)$ and $U_T(h, \psi) = U_T(h, y)$. Therefore, we uniquely specify as:

$$w_T^u(h, \psi) = f(y, \bar{z}, h) - \frac{c_v}{q(\theta_T^u(h, y))},$$

and hence $w_T^u(h, \psi) = w_T^u(h, y)$.

The beginning of age T value of the firm previously matched is

$$F_T(h, z, \psi) = (1 - \lambda_e p(\theta_T(w, h, y))) F_T^b(h, z, y),$$

so $F_T(h, z, \psi) = F_T(h, z, y)$.

Therefore, we can see that (S_T) holds.

We are ready to go back to age $T - 1$. The value of a worker that has not found a job at the search stage is:

$$U_{T-1}^n(h, \psi) = b + \beta \sum_{\{y'\}} \Lambda(y' | y) U_T(h, y'),$$

so $U_{T-1}^n(h, \psi) = U_{T-1}^n(h, y)$.

At the bargaining stage, if an agreement can be reached through Nash-bargaining, the value for a worker of remaining in the match is:

$$(1 - \tau) w_{T-1}^b(h, z, \psi) + \beta \sum_{\{s'\}} \Lambda(s' | s) \left\{ (1 - \delta) V_T(h', z', y') + \delta U_T(h', y') \right\},$$

while the outside option at this stage is $U_{T-1}^n(h, y)$. The value of the firm of remaining in the match is:

$$-w_{T-1}^b(h, z, \psi) + \sum_{\{s'\}} \Lambda(s' | s) \left\{ f(y, z', h) + \beta (1 - \delta) F_T(h', z', y') \right\},$$

and the outside value of the firm is fixed at zero.

Thus, at age $T - 1$, the bargaining problem for the continuing match is:

$$\max_{\{w^b\}} \left[(1 - \tau) w^b + \beta \sum_{\{s'\}} \Lambda(s' | s) \left\{ (1 - \delta) V_T(h', z', y') + \delta U_T(h', y') \right\} - U_{T-1}^n(h, y) \right]^\xi \\ \times \left[-w^b + \sum_{\{s'\}} \Lambda(s' | s) \left\{ f(y, z', h) + \beta (1 - \delta) F_T(h', z', y') \right\} \right]^{1-\xi}$$

and the joint surplus is:

$$-\tau w^b - U_{T-1}^n(h, y) + \sum_{\{s'\}} \Lambda(s' | s) \left\{ f(y, z', h) + \beta ((1 - \delta) (V_T(h', z', y') + F_T(h', z', y')) + \delta U_T(h', y')) \right\}.$$

The cutoff productivity $z_{T-1}^b(h, \psi)$ is the lowest z such that the surplus of both firm and worker are non-negative, and $z_{T-1}^b(h, \psi) = z_{T-1}^b(h, y)$ as above.

If $z \geq z_{T-1}^b(h, y)$, the bargaining problem has a unique solution:

$$w_{T-1}^b(h, z, \psi) = \xi \left\{ \sum_{\{s'\}} \Lambda(s' | s) (f(y, z', h) + \beta (1 - \delta) F_T(h', z', y')) \right\} \\ + (1 - \xi) (1 - \tau)^{-1} \left\{ U_{T-1}^n(h, y) - \beta \sum_{\{s'\}} \Lambda(s' | s) ((1 - \delta) V_T(h', z', y') + \delta U_T(h', y')) \right\},$$

otherwise the bargaining fails and the employed worker and the firm receive the outside value. We can see that $w_{T-1}^b(h, z, \psi) = w_{T-1}^b(h, z, y)$.

Therefore, at the bargaining stage the employed worker's value is:

$$V_{T-1}^b(h, z, \psi) = (1 - \tau) w_{T-1}^b(h, z, y) + \beta \sum_{\{s'\}} \Lambda(s' | s) \left\{ (1 - \delta) V_T(h', z', y') + \delta U_T(h', y') \right\},$$

if $z \geq z_{T-1}^b(h, y)$ and $V_{T-1}^b(h, z, \psi) = U_{T-1}^n(h, y)$ otherwise. The firm's value is:

$$F_{T-1}^b(h, z, \psi) = -w_{T-1}^b(h, z, y) + \sum_{\{s'\}} \Lambda(s' | s) \left\{ f(y, z', h) + \beta (1 - \delta) F_T(h', z', y') \right\},$$

if $z \geq z_{T-1}^b(h, y)$ and $F_{T-1}^b(h, z, \psi) = 0$ otherwise. Thus, we can write $V_{T-1}^b(h, z, \psi) = V_{T-1}^b(h, z, y)$ and $F_{T-1}^b(h, z, \psi) = F_{T-1}^b(h, z, y)$.

On the other hand, the value of the worker that has found an alternative job offer is:

$$V_{T-1}^a(w^a, h, \bar{z}, \psi) = (1 - \tau) w^a + \beta \sum_{\{y'\}} \Lambda(y' | y) \left\{ (1 - \delta) V_T(h', \bar{z}, y') + \delta U_T(h', y') \right\},$$

so $V_{T-1}^a(w^a, h, \bar{z}, \psi) = V_{T-1}^a(w^a, h, \bar{z}, y)$. The value of the newly matched firm is:

$$G_{T-1}(w^a, h, \bar{z}, \psi) = f(y, \bar{z}, h) - w^a + \beta (1 - \delta) \sum_{\{y'\}} \Lambda(y' | y) F_T(h', \bar{z}, y'),$$

and hence $G_{T-1}(w^a, h, \bar{z}, \psi) = G_{T-1}(w^a, h, \bar{z}, y)$.

Then, the free-entry condition is:

$$c_v \geq q(\theta_{T-1}(w, h, \psi)) G_{T-1}(w, h, \bar{z}, y)$$

and $\theta_{T-1}(w, h, \psi) \geq 0$ with complementary slackness. It follows that:

$$\theta_{T-1}(w, h, \psi) = q^{-1} \left(\frac{c_v}{f(y, \bar{z}, h) - w + \beta(1-\delta) \sum_{\{y'\}} \Lambda(y' | y) F_T(h', \bar{z}, y')} \right)$$

if $c_v \leq f(y, \bar{z}, h) - w + \beta(1-\delta) \sum_{\{y'\}} \Lambda(y' | y) F_T(h', \bar{z}, y')$, and $\theta_{T-1}(w, h, \psi) = 0$ otherwise, so $\theta_{T-1}(w, h, \psi) = \theta_{T-1}(w, h, y)$ as the right hand side depends on ψ only through y . Equivalently,

$$w = f(y, \bar{z}, h) + \beta(1-\delta) \sum_{\{y'\}} \Lambda(y' | y) F_T(h', \bar{z}, y') - \frac{c_v}{q(\theta_{T-1}(w, h, y))},$$

if $c_v \leq f(y, \bar{z}, h) - w + \beta(1-\delta) \sum_{\{y'\}} \Lambda(y' | y) F_T(h', \bar{z}, y')$, and $\theta_{T-1}(w, h, \psi) = 0$ otherwise.

Thus, before the search stage the value of the matched worker is:

$$\begin{aligned} V_{T-1}(h, z, \psi) &= \max_{\{w^a\}} \lambda_e p(\theta_{T-1}(w^a, h, y)) \left\{ w^a (1-\tau) + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1-\delta) V_T(h', \bar{z}, y') \right. \\ &\quad \left. + \delta U_T(h', y')) \right\} + (1 - \lambda_e p(\theta_{T-1}(w^a, h, y))) V_{T-1}^b(h, z, y), \\ &= \max_{\{w^a\}} \lambda_e \left\{ -c_v \theta_{T-1}(w^a, h, y) (1-\tau) + p(\theta_{T-1}(w^a, h, y)) \left\{ f(y, \bar{z}, h) (1-\tau) \right. \right. \\ &\quad \left. \left. + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1-\delta) F_T(h', \bar{z}, y') (1-\tau) + (1-\delta) V_T(h', \bar{z}, y') + \delta U_T(h', y')) \right. \right. \\ &\quad \left. \left. - V_{T-1}^b(h, z, y) \right\} \right\} + V_{T-1}^b(h, z, y), \\ &= \max_{\theta \geq 0} \lambda_e \left\{ -c_v \theta (1-\tau) + p(\theta) \left\{ f(y, \bar{z}, h) (1-\tau) \right. \right. \\ &\quad \left. \left. + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1-\delta) F_T(h', \bar{z}, y') (1-\tau) + (1-\delta) V_T(h', \bar{z}, y') + \delta U_T(h', y')) \right. \right. \\ &\quad \left. \left. - V_{T-1}^b(h, z, y) \right\} \right\} + V_{T-1}^b(h, z, y), \end{aligned}$$

so if $(1-\tau) f(y, \bar{z}, h) + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1-\delta) F_T(h', \bar{z}, y') (1-\tau) + (1-\delta) V_T(h', \bar{z}, y') + \delta U_T(h', y')) \leq V_{T-1}^b(h, z, y)$ then the solution is zero, and otherwise the objective function is strictly concave in θ . Thus, this problem has a unique solution $\theta_{T-1}^a(h, z, \psi)$. Then, $\theta_{T-1}^a(h, z, \psi) = \theta_{T-1}^a(h, z, y)$ and $V_{T-1}(h, z, \psi) = V_{T-1}(h, z, y)$ as above. Therefore, we uniquely specify:

$$w_{T-1}^a(h, z, \psi) = f(y, \bar{z}, h) + \beta(1-\delta) \sum_{\{y'\}} \Lambda(y' | y) F_T(h', \bar{z}, y') - \frac{c_v}{q(\theta_{T-1}^a(h, z, y))},$$

and hence $w_{T-1}^a(h, z, \psi) = w_{T-1}^a(h, z, y)$.

Similarly we have at the beginning of age $T - 1$ value of unemployment:

$$\begin{aligned}
U_{T-1}(h, \psi) &= \max_{\{w^u\}} \lambda_u p(\theta_{T-1}(w^u, h, y)) \left\{ w^u (1 - \tau) + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) V_T(h', \bar{z}, y') \right. \\
&\quad \left. + \delta U_T(h', y')) \right\} + (1 - \lambda_u p(\theta_{T-1}(w^u, h, y))) U_{T-1}^n(h, y), \\
&= \max_{\{w^u\}} \lambda_u \left\{ -c_v \theta_{T-1}(w^u, h, y) (1 - \tau) + p(\theta_{T-1}(w^u, h, y)) \left\{ f(y, \bar{z}, h) (1 - \tau) \right. \right. \\
&\quad \left. \left. + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) F_T(h', \bar{z}, y') (1 - \tau) + (1 - \delta) V_T(h', \bar{z}, y') + \delta U_T(h', y')) \right. \right. \\
&\quad \left. \left. - U_{T-1}^n(h, y) \right\} \right\} + U_{T-1}^n(h, y), \\
&= \max_{\theta \geq 0} \lambda_u \left\{ -c_v \theta (1 - \tau) + p(\theta) \left\{ f(y, \bar{z}, h) (1 - \tau) + \right. \right. \\
&\quad \left. \left. \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) F_T(h', \bar{z}, y') (1 - \tau) + (1 - \delta) V_T(h', \bar{z}, y') + \delta U_T(h', y')) \right. \right. \\
&\quad \left. \left. - U_{T-1}^n(h, y) \right\} \right\} + U_{T-1}^n(h, y),
\end{aligned}$$

so if $f(y, \bar{z}, h) (1 - \tau) + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) F_T(h', \bar{z}, y') (1 - \tau) + (1 - \delta) V_T(h', \bar{z}, y') + \delta U_T(h', y')) \leq U_{T-1}^n(h, y)$ then the solution is zero, and otherwise the objective function is strictly concave in θ . Thus, this problem has a unique solution $\theta_{T-1}^u(h, \psi)$. Then, $\theta_{T-1}^u(h, \psi) = \theta_{T-1}^u(h, y)$ and $U_{T-1}(h, \psi) = U_{T-1}(h, y)$. Therefore, we uniquely specify:

$$w_{T-1}^u(h, \psi) = f(y, \bar{z}, h) + \beta \sum_{\{y'\}} \Lambda(y' | y) (1 - \delta) F_T(h', \bar{z}, y') - \frac{c_v}{q(\theta_{T-1}^u(h, y))},$$

and hence $w_{T-1}^u(h, \psi) = w_{T-1}^u(h, y)$.

The beginning of age $T - 1$ value of the firm previously matched is:

$$F_{T-1}(h, z, \psi) = (1 - \lambda_e p(\theta_{T-1}(w, h, y))) F_{T-1}^b(h, z, y),$$

so $F_{T-1}(h, z, \psi) = F_{T-1}(h, z, y)$.

Therefore, we can see that (S_T) implies (S_{T-1}) . Hence, by induction, (S_t) holds for $t = 1, \dots, T$, i.e. $U_t, V_t, F_t, G_t, w_t^u, w_t^a, w_t^b, z_t^b$ and θ_t are uniquely computed and they depend on ψ only through y for $t = 1, \dots, T$. ■

B Expected Present Discounted Value of Earnings

We compute the expected present discounted value of earnings, for the case of no ex-ante heterogeneity or human capital depreciation. At age T the value of an unemployed worker with no job offer after the search stage is $U_T^n(h, y) = b$. We denote the expected present discounted value of earnings as $\hat{U}_T^n(h, y) = 0$. At the

bargaining stage the value of an employed worker is $\hat{V}_T^b(h, z, y) = (1 - \tau) w_T^b(h, z, y)$ if $z \geq z_T^b(h, y)$ and $\hat{V}_T^b(h, z, y) = 0$ otherwise. The value for a worker that finds an alternative job offer is $V_T^a(w^a, h, \bar{z}, y) = \hat{V}_T^a(w^a, h, \bar{z}, y) = (1 - \tau) w^a$. At the search stage the earnings value of the workers is evaluated at the equilibrium $\theta_T^a(h, z, y)$:

$$\hat{V}_T(h, z, y) = \lambda_e p(\theta_T^a(h, z, y)) w^a (1 - \tau) + (1 - \lambda_e p(\theta_T^a(h, z, y))) \hat{V}_T^b(h, z, y)$$

evaluated with the optimal policy functions consistent with the BRE. The earnings value of the unemployed worker at the search stage is:

$$\hat{U}_T(h, y) = \lambda_u p(\theta_T^u(h, y)) w^u (1 - \tau) + (1 - \lambda_u p(\theta_T^u(h, y))) \hat{U}_T^n(h, y)$$

evaluated at the optimal policy functions consistent with the BRE. Going back one period, the earnings value of an unemployed worker is:

$$\hat{U}_{T-1}^n(h, y) = 0 + \beta \sum_{\{y'\}} \Lambda(y' | y) \hat{U}_T(h, y')$$

At the bargaining stage, if an agreement can be reached through Nash-bargaining, the earnings value for a worker of remaining in the match is:

$$\hat{V}_{T-1}^b(h, z, y) = (1 - \tau) w_{T-1}^b(\cdot) + \beta \sum_{\{s'\}} \Lambda(s' | s) \left\{ (1 - \delta) \hat{V}_T(h', z', y') + \delta \hat{U}_T(h', y') \right\}$$

while the outside option at this stage is $\hat{U}_{T-1}^n(h, y)$. Before the search stage the earnings value of the matched worker is:

$$\begin{aligned} \hat{V}_{T-1}(h, z, y) &= \lambda_e p(\theta_{T-1}(w^a, h, y)) \left\{ w^a (1 - \tau) + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) \hat{V}_T(h', \bar{z}, y') \right. \\ &\quad \left. + \delta \hat{U}_T(h', y')) \right\} + (1 - \lambda_e p(\theta_{T-1}(w^a, h, y))) \hat{V}_{T-1}^b(h, z, y) \end{aligned}$$

At the beginning of age $T - 1$ the earnings value of unemployment is:

$$\begin{aligned} \hat{U}_{T-1}(h, y) &= \lambda_u p(\theta_{T-1}(w^u, h, y)) \left\{ w^u (1 - \tau) + \beta \sum_{\{y'\}} \Lambda(y' | y) ((1 - \delta) \hat{V}_T(h', \bar{z}, y') \right. \\ &\quad \left. + \delta \hat{U}_T(h', y')) \right\} + (1 - \lambda_u p(\theta_{T-1}(w^u, h, y))) \hat{U}_{T-1}^n(h, y) \end{aligned}$$

By backward induction we can compute $\{\hat{V}_t, \hat{V}_t^b, \hat{V}_t^a, \hat{U}_t, \hat{U}_t^n\}$ for all t .