Human Capital and Employment Risks Hedging *

Pascal St-Amour

Faculty of Business and Economics (HEC)
University of Lausanne

Swiss Finance Institute

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Abstract

Both educational expenditures and attainment have increased sharply over the last decades, despite rising prices of education, and stagnating income returns to human capital. This paper emphasizes conditional employment risks hedging as additional motivation for education demand. Job risk diversification through education is strongly evidenced in the data, yet is absent from the Human Capital (HC) literature, whereas agents’ dynamic household choices are not considered in standard unemployment Search and Matching models. A benchmark HC model is thus modified to allow for lower job displacement risk, and higher re-employment probability, in addition to higher income for the better educated. Numerical solutions for optimal dynamic investment in human capital are consistent with observed patterns, such as unemployment duration dependence (stigma), post-re-employment income loss (scarring), and cyclical patterns in education expenditures. The effects of permanent shifts affecting human capital returns in employment risks hedging, and income returns are investigated and shown to be consistent with rising educational expenditures and attainment.

**Keywords** — Demand for education; unemployment duration dependence; unemployment stigma; income scarring; work displacement; re-employment probability.

**JEL classification** — I26, J24, J64, J65
1 Introduction

Educational attainment has increased sharply in the US (see Figure 1), as well as in most countries over the last decades.\footnote{For example, see the special report of The Economist on tertiary education, “The whole world is going to university”, March 28th, 2015.} This remarkable growth in human capital cannot be solely explained by better educational technology; both education expenditure shares of total personal expenditures and real prices have increased over the same period (Figure 2, Panel A). Similarly, the growth in disposable resources cannot be relied upon as sole explanatory factor; education expenditures shares and prices tend to be counter-cyclical, and increase when income falls in recessions (Figure 2, Panel B).

The previous elements suggest that strong, and improving expected returns must have justified the households’ decision to invest more in human capital. These rewards can be separated between the capacity of education to generate higher labour revenues, and its capacity to protect these gains from adverse labour market shocks. The former is partly verified by the income returns to education. Median weekly earnings data suggests that the education gradients are significant, and have increased up to 2000, but have stagnated afterwards (Figure 3).

The employment risk hedging is also a plausible explanation for several reasons. First, incomplete coverage and progressivity of unemployment insurance (UI) programs entail that the income losses associated with unemployment are substantial, and the more so for the higher revenues (and therefore more educated) workers.\footnote{Progressivity obtains through the taxation of UI benefits which entails that net replacement rates (i.e. the percentage of net income that is kept after entering UI coverage) are lower for the higher incomes (OECD, 2015).} Moreover, the recent evolution in UI programs has been detrimental to the high incomes (Figure 4). Put differently, the value at risk is much more important, and increasingly so for the more educated. Second, education fortunately provides genuine insurance against employment hazards. While unconditional unemployment rates are much lower (Figure 5), so is the conditional job loss (i.e. displacement) risk, whereas post-unemployment job finding (re-employment) is much faster the higher the educational attainment (Figure 7 A, and
B). Since all employment risks are strongly cyclical (Figure 6), education thus provides non-negligible hedging against otherwise undiversifiable macro shocks.

Motivated by these data features, this paper asks two questions. First, we investigate how the inclusion of (partially) diversifiable employment risks through education affects the agents’ demand for human capital. In particular, our objective is to devise a simple framework that is capable of reproducing a number of key facts, such as unemployment duration dependence (stigma), fall in income if re-employed after unemployment spells (scarring), the cyclical properties of education demand, as well as the moral hazard responses to changes in UI characteristics. Our simulation results shows that employment risks hedging motives are not innocuous and account for about 22% of the investment and human capital levels.

Second, we study how permanent shocks to human capital returns can affect the dynamic investment decisions made by households. For that purpose, we investigate whether changes in the income rewards, such as the increased education premia up to 2000, or the deterioration in UI programs coverage after that period can explain the rise in the demand for education. We also look at changes in conditional employment risks, such as adverse movements in re-employment and displacement after 2000, as potential explanations for better educational attainment.

Including employment risks hedging motives in the demand for human capital is warranted for both normative and positive reasons. First, the uncertainty associated with unemployment is largely viewed as undiversifiable, both through market-provided and through self-insurance. Allowing for the latter imposes a reassessment of the optimality of UI policies (Pavoni, 2009). Second, the design of UI programs is also likely to be affected by self-insuring through education. For example, imposing a flatter UI replacement schedule decreases the motivations for the lower-educated workers to invest in education, but raises the stakes for the better educated ones, and therefore their demand for additional hedging through human capital. Positive education gradients in
income implies that the resulting changes in the optimal investment will affect the income
distribution, therefore raising additional equity issues.

Third, the private benefits to education are likely to be seriously under-estimated if
hedging components are abstracted from. These gains affect the desirability of investing
public funds in ex-post income security measures, such as UI programs, versus in ex-
ante preventive actions, such as education in order to counter social costs related to
employment fluctuations. More generally, appending the capacity to self-ensure against
employment risks directly affects the welfare costs of macroeconomic fluctuations.

From a theoretical perspective, when compared to income premia motivations, em-
ployment risks hedging through human capital has received little attention in academic
research. Self-insurance against conditional employment risks is certainly present in the
Search and Matching (SM) literature (Burdett and Mortensen, 1980; Mortensen and
Pissarides, 1994), but this is achieved through a static, and often mechanic setup. Indeed,
employment risks stem from either TFP (Shimer, 2005; Moscarini and Postel-Vinay, 2013)
or idiosyncratic shocks (Bagger et al., 2014) against which re-employment is accelerated
through costly, yet static efforts by the unemployed. Furthermore, displacement risks are
hedged by experience which is acquired mechanically through work tenure, or by firm-
decided investment in training. These models do not involve dynamic choices by agents
facing such elements as economic depreciation (i.e. obsolescence) or path-dependent
adjustment costs of the human capital stock, and none studies continuous decisions that
are made across the employment statuses.\footnote{For example, Charlot and Malherbet (2013); Decreuse and Granier (2013) allow for one-shot
education choices made during younger age only.} Put bluntly, the SM literature does not
incorporate human capital decisions made by households.

Conversely, the Human Capital (HC) literature seldom ventures in the conditional risk
arena that SM research specializes in. Whereas most of HC contributions incorporate the
usual income enhancement motives (Ben-Porath, 1967; Heckman, 1976; Kredler, 2014),
the employment risks remain undiversifiable (Rogerson and Schindler, 2002; Krebs, 2003;
Huggett et al., 2011; Cervellati and Sunde, 2013). None consider the human-capital
dependence of displacement, scarring, re-employment, or duration dependence concerns that should affect the desirability of education.

This paper innovates by combining elements of both the SM and HC strands. More precisely, we consider dynamic human capital accumulation that is non-firm-specific, and where conditional employment risks hedging motives featured in the SM frameworks are appended to the more traditional income premia motivations studied by the HC literature. As for SM models, displacement and re-employment can be affected by workers’ decisions. Unlike SM however, these decisions are dynamic, and made across age and employment statuses. We also depart from SM and follow the HC tradition in limiting our analysis to partial, rather than general equilibrium in that the optimal allocation is derived taking the employment hazard and income functions as given. As such, our analysis can be considered as a first step in bringing *bona fide* human capital into a full-fledged dynamic general equilibrium favoured by SM methods.

Our modelling strategy features infinitely-lived, risk-neutral agents that are heterogeneous in both their human capital attainment, and their employment status (employed, unemployed). Access to financial markets is limited, and inter-temporal consumption allocation is achieved by investing in their human capital exclusively. The latter is depreciable, and continuously adjusted through deliberate (non-mechanic) household investment decisions that are subject to diminishing returns. Human capital is assumed to be observable and valued by employers as reflected in higher wages, lower displacement, and higher re-employment probabilities for the better educated. As mentioned earlier, this part of the equation is taken as given, and not solved endogenously.

Under the assumption of Poisson arrival rates for changes in employment statuses, the continuous-time agent’s problem is iso-morphic to endogenous discounting, which complicates the solution of the Hamilton-Jacobi-Bellman joint system of first-order differential equations. We therefore resort to numerical projection methods based on Chebyshev polynomials, with shape-preserving constraints guaranteeing the monotonicity and curvature of the pair of status-dependent value functions. The model is parametrized, solved
and simulated with the calibration chosen so as to reproduce the observed unemployment, displacement, and re-employment rates as well as the mean human capital investment share of income.

Our baseline parametrization yields optimal allocation rules that are intuitively appealing, and consistent with both intuition, and empirical regularities. First, as expected, welfare is increasing in human capital, and is always higher for the employed. Second, we find that optimal investment level is higher for the employed, whereas the share of revenues allocated to education is higher for the unemployed. We also highlight non-monotone effects of human capital on investment that stem from two opposing forces. On the one hand, progressive UI programs imply that the expected income loss is more important for the unemployed better educated. This income gap effect is dominant at high education levels. On the other hand, higher human capital diversifies the employment risks faced by the agents, and thereby lowers the desirability of investing further resources in education. This effect is dominant at low education levels. It follows that investment levels and shares fall in human capital for low education levels, and increase for higher education.

Importantly, our calibration yields two unique, and dynamically stable steady-state levels of human capital (one per status) and the latter is higher for the employed. Coupled with our earlier findings, these dynamic features play a crucial role in ensuring that the model predictions accord with the empirical facts. First, displacement of a long-tenured worker entails an optimal decline in human capital for the duration of the unemployment spell until a new (lower) steady-state level is attained. As the re-employment probabilities increase in human capital, it follows that re-employment probabilities fall endogenously with duration, consistent with the observed duration dependence (stigma effects). Similarly, the optimal fall in human capital following displacement of long-tenured workers triggers a corresponding decline in income. Any re-employment therefore occurs at a necessarily lower level of human capital, and therefore lower wages, consistent with the evidence on scarring effects of unemployment. Finally, because optimal investment shares
increase in human capital, and are higher for the unemployed, displacement in recessions entails an immediate rise in education expenditures shares, followed by a graduate fall as human capital drops towards its lower steady-state value, consistent with the cyclical properties that are observed in the data.

Having confirmed the model’s concordance with the empirical regularities, our next objective is to assess the effects of permanent changes in the returns to human capital. For that purpose, we consider a comparative statics exercise that involves two modifications in the income returns, and two for the employment risks motivations. In particular, we look at the effects of an increase in the human capital premia in employment revenues (as observed in the data before 2000), as well as a decrease in net UI coverage that is more important for the better-educated (as observed in the data after 2000). We then consider a deterioration in re-employment probabilities, as well as an increase in displacement rates that is more unfavorable for the less-educated (as observed in the data after 2000). The effects of changes in UI coverage in particular highlight the moral hazard responses in the form of more self-insurance when publicly-provided employment risk insurance deteriorates. We conclude by arguing that the first three of the four changes could justify the rise in educational expenditures and attainment displayed in Figure 1.

The rest of the paper is organized as follows. We first review the main stylized facts linking human capital and labor market conditions in Section 2. Next, the model is outlined in Section 3. The optimal allocations are detailed in Section 4, and contrasted with the empirical regularities, starting first with the baseline calibration, followed by a comparative exercise in which the key parameters are altered. A conclusion in Section 5 briefly reviews the main findings, while discussing limitations and proposing avenues for future research.
2 Some stylized facts on human capital and labour market conditions

Figure 1 plots the rise in educational attainment measured in percentage of the US population aged 25 and over. It depicts the clear constant fall in the population with less than a high school degree over the last 45 years. Although a number of these agents went on to obtain their diploma, the population share with only a high school degree starts falling after the 90’s. Conversely, the share of persons with at least some college education increased throughout the period.

Such an increase in educational attainment could be achieved through constant inputs and better technology. Panel A of Figure 2 shows that this is apparently not the case; both the education real prices, and the share of personal expenditures allocated to education increase over the same period. Increased demand for education could be fueled by higher income. However, Panel B which plots the de-trended series shows that both education prices and shares are counter-cyclical; they tend to increase following the recessions of the mid-70’s, early 80’s, 90’s and 2000 and 2008, and fall in the subsequent recoveries. More disposable resources alone is therefore not a convincing argument for more education demand.

Taken together, these elements suggest instead that increased expected rewards rather than better technology, falling costs, or richer households could explain the increase in the demand for human capital. Figure 3 displays the real (base year 1984) median weekly earnings by education attainment level. Both the levels in A, and deviations from high school earnings indicate a substantial income premia associated with education, with workers with Bachelor degrees earning between 242$ and 274$ more per week than those with less than high school. Moreover, this premia is relatively a-cyclical, and increases continuously up until early 2000, before stagnating afterwards. All in all, the existence of a positive income return to human capital would be consistent with the rise in educational
attainment only up to a certain point; the stagnation in premia in the second half of our sample is hinting that other elements might be at play.

Unemployment costs are mainly associated with the drop in revenue that job loss entails. This is reflected in part in Figure 4 which plots the evolution in UI net replacement rates (NRR). Since UI benefits are taxable income, NRR is a more appropriate measure of the income gap between employed and unemployed. Three elements stand out. First, the income costs of unemployment are substantial, with NRR percentages ranging between 30 and 50% in 2012. Moreover, the UI system is quite progressive; higher income (which are also the more educated) suffer proportionally more than lower incomes. Third, the UI evolution is not favorable to the unemployed, the NRR are falling continuously after 2003. This analysis suggests that the unemployment income gap is larger and increasing for the more educated workers. However, if education also permits a lowering of the unconditional unemployment probability or the conditional risks of displacement and/or an increase in the probability of re-employment, then these elements would induce a strong employment risks hedging motive for investing in human capital.

Figure 5 reports the unemployment rates by education levels. It clearly indicates that human capital is a powerful hedging instrument against unconditional unemployment risk. Indeed, the difference between the unemployment rates of workers with less than a high school diploma and those with at least a Bachelor degree is very counter-cyclical and varies between 3.9% in recoveries, and 11.1% at the through of the 2008 recession, with a median value of 6.1%. However, this spread is also falling up to 2005, and increasing thereafter. Unconditional unemployment hedging is therefore a likely, but incomplete explanation for the increased demand in education.

Figure 6 displays the evolution of the monthly labor market flows from the employed and unemployed statuses. It shows that displacement and re-employment are strongly cyclical series. Moreover, we witness an important deterioration after 2000, with displacement (re-employment) increasing (decreasing). Figure 7 relies on Displaced Worker Survey data to show that how these macro effects are not distributed evenly across human
capital levels. In Panel A, one-year displacement rates are plotted against educational attainment for three sample years. Regardless of the period, a clear negative education gradient is apparent, with less educated workers suffering a much higher displacement risk. Moreover, both the displacement level and the education gradient increase sharply in 1994 and 2010, i.e. after the recessions of 1991, and 2008, when compared to 2000, i.e. a pre-2001 recession period. Similarly, Panel B shows that one-year re-employment probabilities are associated with a strong positive education gradient, with more educated workers facing a higher reentry probability. Again, both levels and slope are cyclical; re-employment falls after a recession, and the more so for the less-educated workers. Panel C confirms the findings in Figure 3 that earnings are strongly and positively related to education, yet are relatively a-cyclical. Finally, Panel D shows that the income loss associated with unemployment is not only related to low NRR. Indeed, those workers who are re-employed following an unemployment spell usually suffer from a substantial income loss (scarring), which increases importantly in recessions, and also tends to be worse for the low human capital workers.

Overall, these stylized facts show that the increased human capital attainment cannot be explained by improved education technology, falling prices, or increased income. Moreover, the income premia is certainly a valid motive for education, but only up to a point. On the other hand, the income gap associated with unemployment is substantial, is higher for the more educated, and is increasing over time. Fortunately, education is a very good hedge against the high unconditional unemployment, high displacement and low re-employment risks, as well as higher scarring risk that are associated with recessions. Taken together, these elements warrant appending partially diversifiable employment risks to the more traditional income motive in the decision to invest in human capital.
3 Model

Consider an economy populated by agents who are characterized by two sources of heterogeneity: Human capital, and labour market status. The former is deterministic, continuously accumulable and publicly measurable. It provides no direct utility to the agent, but is valued by all employers. This is reflected in more favourable conditions with respect to wages, firing and hiring for agents with higher human capital. From this perspective, human capital is therefore productive, rather than cultural, and general, rather than firm-specific. Employment statuses are stochastic and take two values: employed and unemployed, whereby the transition matrix is agent-specific, in that it depends on the accumulated level of human capital.

**Human capital accumulation**  Each agent has a deterministic and observable level of human capital $H \in \mathbb{R}_+$, whose law of motion is status-independent and given by:

$$\dot{H}_t = -\delta H_t + AI_t^\alpha H_t^{1-\alpha}, \quad \alpha, \delta \in (0, 1) \tag{1}$$

The human capital accumulation (1) is standard, (e.g. Ben-Porath, 1967; Heckman, 1976; Kredler, 2014) and captures continuous, as opposed to period-specific (e.g. young age) investment. The gross investment function $I^g(I_t, H_t) = AI_t^\alpha H_t^{1-\alpha}$ is monotone increasing and concave in its arguments. Depreciation can be interpreted as technological obsolescence in the sense that depreciated capital adversely affects employment opportunities, as will be discussed next.

**Employment statuses**  Second, a person’s labour market status is stochastic and follows a Poisson process with each agent being either employed ($i = e$), or unemployed ($i = u$). Importantly, the arrival intensity is assumed to be dependent of the human capital level. More specifically, let $T^i$, be the random time of job displacement from current employment ($i = u$), or re-employment from current unemployment ($i = e$), with
Poisson arrival intensities:

\[
\lambda^i(H_t) = \lim_{\tau \to 0} \frac{1}{\tau} \Pr \left[ t < T^i < t + \tau \mid H_t \right], \quad i = u, e
\]  

(2)

where \( \lambda^i : \mathbb{R}_+ \to \mathbb{R}_{++} \) satisfies

\[
\lambda^u_H \leq 0; \quad \lambda^u_{HH} \geq 0; \quad \lambda^e_H \geq 0; \quad \lambda^e_{HH} \leq 0;
\]

As illustrated in Figure 8, the intensities are assumed to be bounded below by:

\[
\lambda^e_0 = \lim_{H \to 0} \lambda^e(H); \quad \lambda^u_0 = \lim_{H \to \infty} \lambda^u(H).
\]

An agent can decrease his displacement intensity \( \lambda^u \), or increase his re-employment intensity \( \lambda^e \) by augmenting his human capital through investment, subject to diminishing returns. The time \( t \) probability of remaining employed \((k = u)\) or remaining unemployed \((k = e)\) up to \( t + s \) is therefore:

\[
P_t \left[ T^k > t + s \right] = \exp \left[ - \int_t^{t+s} \lambda^k(H) d\tau \right], \quad k = u, e.
\]

(3)

**Income process**  The income process \( Y^i(H_t) \) is status-, and human-capital-dependent, and is monotone increasing, concave in human capital, subject to:

\[
0 < Y^u(H) < Y^e(H)
\]

\[
0 < Y^u_H(H) < Y^e_H(H)
\]

\[
0 > Y^e_{HH}(H) > Y^e_{HH}(H)
\]

(4)

Higher level of human capital thus yield higher employment income \( Y^e(H) \), subject again to diminishing returns. Unemployment income \( Y^u(H) \) is lower, also increasing and concave, but subject to more important decreasing returns. The latter reflects the imperfect coverage, and progressivity of UI programs.
**Preferences**  All agents are infinitely-lived, and risk-neutral, and select dynamic investment in human capital $I$ to maximize expected discounted (at rate $\rho$) utility, subject to a budget constraint, and taking arrival rate (2) and income (4) functions as given. We assume that agents do not have access to financial assets, but achieve inter-temporal smoothing through human capital only.\(^4\) Let $V^i(H_0)$ denote the time-0 value function conditional upon status $i$. Under the Law of Iterated Expectations, for statuses $i,j = e,u; i \neq j$, the agent’s problem iso-morphic to endogenous discounting:

$$V^i(H_0) = \max \left\{ I \right\} \int_0^\infty \exp \left[ - \int_0^t (\rho + \lambda^j(H_s)) \, ds \right] \left[ Y^i(H_t) - I_t + \lambda^j(H_t) V^j(H_t) \right] \, dt$$  \hspace{1cm} (5)

subject to human capital accumulation (1). The corresponding Hamilton-Jacobi-Bellman (HJB) representation of (5) is given by:

$$0 = \max \left\{ I^g \right\} - \rho V^i(H) - \lambda^j(H) \left[ V^i(H) - V^j(H) \right] + Y^i(H) - I$$
$$- \delta HV^i_H(H) + AI^{\alpha} H^{1-\alpha} V^i_H(H).$$  \hspace{1cm} (6)

Observe that this formulation with diminishing returns in gross investment is equivalent to assuming linear diffusion, and convex adjustment costs:

$$0 = \max \left\{ I^g \right\} - \rho V^i(H) - \lambda^j(H) \left[ V^i(H) - V^j(H) \right] + Y^i(H) - I^g P^g(I^g, H)$$
$$- \delta HV^i_H(H) + I^g V^i_H(H).$$

where the agent-specific cost of education satisfies:

$$P^g(I^g, H) = A^{-(1+\gamma)} \left( \frac{I^g}{H} \right)^\gamma, \quad \gamma \equiv \frac{1-\alpha}{\alpha},$$

\(^4\)Note that no access to financial markets entails that all investment plans must be self-financing, i.e. $I_t \leq Y^i_t, \forall t$. This constraint is not imposed in the solution method; instead calibration ensures that consumption $C_t = Y^i_t - I_t$ is non-negative.
an increasing function of the gross investment to human capital ratio. This suggests that personal education costs $P^g(I^g, H)$ are higher, but falling faster in $H$ at low education levels.

The first-order condition to the agent’s problem (6) is given as:

$$I^i = H \left[ A \alpha V^i_H(H) \right]^{\frac{1}{1-\alpha}}$$

Substituting back into the objective function reveals that the joint HJB system simplifies to:

$$0 = -\rho V^e(H) - \lambda^e(H) [V^e(H) - V^u(H)] + Y^e(H)$$
$$- \delta HV^u_H(H) + \kappa H \left[ AV^u_H(H) \right]^{\frac{1}{1-\alpha}},$$
$$0 = -\rho V^u(H) - \lambda^u(H) [V^u(H) - V^e(H)] + Y^u(H)$$
$$- \delta HV^e_H(H) + \kappa H \left[ AV^e_H(H) \right]^{\frac{1}{1-\alpha}},$$

(7)

for $\kappa \equiv (1 - \alpha)\alpha^{\frac{\alpha}{1-\alpha}}$.

The solution to the first-order differential system (7) is nontrivial for two reasons. First, the two value functions $[V^e(H), V^u(H)]$ must be solved jointly. Second, and more importantly, the Poisson hypothesis entails that the discount rates are not constant, but depend on the current human capital state via its effect on the intensities $\lambda_i(H)$. It follows that no analytical solutions are attainable, and that numerical approaches must be used.

**Projection method** The computational solution we resort to relies on projection methods, and is based on Chebyshev polynomials (Dangl and Wirl, 2004; Judd, 1992), subject to shape-preserving restrictions (Cai and Judd, 2013). More precisely, it uses the following steps:

1. Set state space $H \in [a, b]$, which is normalized to $x(H) \in [-1, 1]$

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5 The calibration presented in Table 1 implies $\gamma = 3$, so that education costs are increasing and convex in the gross-investment to capital ratio.
2. We approximate $V^e(H), V^u(H)$ by Chebyshev polynomials:

$$V^i(H) = \sum_{j=0}^{M-1} c^i_j T_j(x), \text{ where } T_j(x) = \cos[j \arccos(x)];$$  \hspace{1cm} (8)

3. Compute (analytically) $V^i_H(H), V^i_{HH}(H)$ from the Chebyshev polynomial (8). Substitute along with $V^i(H)$ in HJB’s (7).

4. Find $(c^e, c^u) \in \mathbb{R}^{2M}$ that minimize the $L^2$ norm over (7) which are evaluated at $M$ nodes in $[a, b]$, subject to monotonicity, concavity:

$$V^i_H(H) \geq 0, \quad V^i_{HH}(H) \leq 0$$

that are evaluated at $N > M$ nodes in $[a, b]$.

**Functional forms and calibration**  Solving the model implies setting the functional forms for the arrival intensities (2), as well as for the income process (4). We therefore set:

$$\lambda^i(H) = \lambda^i_0 + \lambda^i_1 H^{-\xi^i}, \quad \xi^i > -1$$  \hspace{1cm} (9)

and

$$Y^i(H) = \beta^i_0 + \beta^i_1 H^{\beta^i_2}, \quad \beta^i_2 \in (0, 1).$$  \hspace{1cm} (10)

The model’s parameters $\theta = (\alpha, \beta, \delta, \lambda, \xi, \rho)$ are calibrated to satisfy the monotonicity and curvature conditions, and to replicate the observed unconditional unemployment, displacement, and re-employment probabilities. The selected parameters’ values are reported in Table 1.

**Simulation**  Further insights on the model’s performance can be obtained through its simulation. For that purpose, we run the following procedure. For agents $j = 1, 2, \ldots, J$ we initialize the dynamic process by drawing the initial status $S_{j,0} \sim \{e, u\}$ using the
observed unemployment rate, and by drawing $H_{j,0} \sim [a, b]$ for the initial capital level. Then, for periods $t = 0, 1, 2, \ldots, T$, and for each agent $j$:

1. We set $i = S_{j,t}$, and interpolate the optimal rules in order to compute investment, and welfare, and use the intensity function (9) and income function (10) to compute:

$$I_{j,t} = I^i(H_{j,t}),$$
$$V_{j,t} = V^i(H_{j,t}),$$
$$\lambda_{j,t} = \lambda^i(H_{j,t}),$$
$$Y_{j,t} = Y^i(H_{j,t}).$$

2. Use the human capital accumulation (1), and the status probability (3) to update capital and status as:

$$H_{j,t+1} = H_{t+1}(I_{j,t}, H_{j,t}),$$
$$S_{j,t+1} \sim \exp[-\lambda_{j,t}].$$

This procedure is repeated over $T = 150$ periods, for a population of $J = 10^6$, for a population of $J = 10^6$ individuals. The first burn-in period of 50 is discarded, and the sample means are computed over the remaining 100 periods. The resulting simulated moments are reported in Table 2. It confirms that the observed statistics (1st column) with respect to the unemployment rate $u = 0.076$, the displacement $\text{Pr}[u' \mid e] = 0.056$, and re-employment $\text{Pr}[e' \mid u] = 0.610$, as well as the education share of income $I/Y = 0.056$ are reproduced quite well by the baseline calibration (2nd column).
4 Results

4.1 Baseline results

Figure 9 plots our baseline results. First, in Panel A, the displacement risks are lower, decreasing, and convex whereas the re-employment probabilities are higher, monotone increasing and concave in health. Both functions correctly reproduce the observed range, and shapes found in the data (Figure 7, Panels A and B). Next, the income levels in Panel B indicate a higher, increasing, and steeper revenue function for the employed, compared to the unemployed, consistent with the progressive UI net replacement rates (Figure 4).

The optimal investment indicates that the level of education expenditures is always higher for the employed (Panel C), whereas the share of labor revenues allocated to education (Panel D) is higher for the unemployed. Since the latter are strictly less than one, this confirms that investment plans are always feasible, i.e. $C_i^i(H) = Y_i^i(H) - I_i^i(H) > 0, \forall i, H$. Due to the opposing forces of employment risks hedging and income gaps motives, both investment levels and shares are non-monotone in human capital level. First, in Panel A, diminishing returns to employment risks hedging entail that exogenous increases in $H$ lead to falls in displacement (increases in re-employment) probabilities are stronger at low $H$ than at high human capital levels. Put differently, the employment risk hedging motive for investing falls more rapidly in $H$ for the less educated than for the more educated workers. Conversely, in Panel B, the progressivity of net replacement rates implies that the income gap $\Delta Y(H) \equiv Y^e(H) - Y^u(H)$ is smaller at low $H$ than at high levels. It follows that exogenous increases in $H$ lead to stronger employment gap motive for investing in education for the more educated, compared to the less educated workers. Consequently, the employment risk hedging motive dominates the income gap motive at low $H$ and both investment levels and shares are falling in $H$ for low education levels, regardless of employment status. After a certain threshold however, income gap effects dominate and both investment levels and shares are increasing in $H$. 
Panel E shows that the model yields two unique (one per status), and dynamically stable steady-state levels of human capital. The steady-state level for the employed ($H^e_{ss} = 1.1755$) is more than 40% higher than that for the unemployed ($H^u_{ss} = 0.8221$), consistent with the unemployment distribution by education levels outlined in Figure 5. Finally, Panel F confirms that welfare is unsurprisingly increasing and concave in $H$, and is always higher for the employed.

Importantly, our results accord with numerous features observed in the data, and outlined by the literature. First, a number of researchers have identified duration dependence in unemployment whereby unemployed workers face lower re-employment probabilities the longer their unemployment spells (Eriksson and Rooth, 2014; Kroft et al., 2013). This unemployment stigma effect is often interpreted as indicating that employers rely on unemployment duration as a sorting mechanism. Figure 10 suggests an alternative interpretation of stigma when human capital is factored in. Indeed, suppose a long-tenured employed worker with steady-state human capital $H^e_{ss}$ loses his job and moves from $\mathbf{1}$ to $\mathbf{2}$ in Panel A. Dynamic stability implies that optimal human capital starts falling towards $H^u_{ss}$ in $\mathbf{3}$, inducing duration-dependent falls in re-employment probabilities from $\mathbf{2}$ to $\mathbf{3}$ in Panel B. Put differently, any unemployment duration stigma from employers would be consistent with the optimal decline in human capital selected by displaced agents.

Moreover, as illustrated in Figure 7, Panel D, a large literature has pointed out that displaced workers are usually re-employed at much less favourable conditions (Carrington and Fallick, 2014; Huckfeldt, 2014; Fang and Silos, 2012; Krebs, 2007; Farber, 2005; Rogerson and Schindler, 2002). These scarring effects are again reproduced endogenously by the model. In Figure 11, a displaced long-tenured worker moves from point $\mathbf{1}$ to $\mathbf{2}$. The optimal dynamic path follows a decline in the level of human capital up towards point $\mathbf{3}$ in Panel A; the unemployed income levels fall accordingly from point $\mathbf{2}$ towards $\mathbf{3}$ in Panel B. Following re-employment, his income moves back to $Y^e(H)$ at point $\mathbf{4}$, and will remain lower than his previous income, until the old steady-state level $H^e_{ss}$ is again reached in the long-run.
Finally, our discussion of the cyclical properties of education demand in Figure 2 showed that the education shares of total consumption are counter-cyclical; they tend to increase in recessions, and fall in the subsequent recoveries. The model’s predictions are consistent with these properties. In Figure 12, long-tenured displaced workers move from \(1\) to \(2\) in Panel A. As discussed earlier, education shares of income are higher for the unemployed (Figure 9, Panel D). Consequently, they move up from \(1\) to \(2\) in Panel B, and then fall as optimal dynamic path follows a decline in human capital from 2 to 3. Re-employment induces an upward shift in human capital growth from \(3\) to \(4\) in Panel A, an immediate fall in education shares from point \(3\) to \(4\) in Panel B, and a subsequent, slower growth in expenditures shares as human capital increases back to its steady-state value \(H^e\) from point \(4\) to \(1\).

4.2 Comparative statics

We now turn to comparative statics analysis. More specifically, we start from the optimal allocation, say \(X = X(H; \theta)\), that is obtained under the baseline parametrization \(\theta\) listed in Table 1. We next modify the model’s deep parameters \(\theta \rightarrow \tilde{\theta}\) in a manner that is either counter-factual or consistent with specific changes observed in the data. We then re-compute the optimal rules \(\tilde{X} = \tilde{X}(H; \tilde{\theta})\) under the assumption that these parametric modifications are permanent, and calculate the percentage changes from the baseline calibration \(%(\tilde{X} - X)\).

4.2.1 Gauging the hedging

We first start with a counter-factual exercise in order to measure the importance of the employment risks hedging motives in the households’ decision to invest in human capital. For that purpose, we remove the ability to adjust exposition to displacement and re-employment risks, and re-calculate the associated optimal allocations. The difference with our baseline allocation thus measure the marginal contribution of hedging to total investment demand.
We thus consider three alternative specifications obtained by shutting down the parameter controlling the endogeneity in the intensity process ($\lambda_1^i$), and setting the base parameter ($\lambda_0^i$) to its data statistic value. Such a change is thus unconditionally neutral in its effect on the intensities, yet is not homogenous and will affect agents differently depending on their human capital level. In particular, removing the endogeneity of the intensity function and adjusting the base parameter so as to maintain average hazard rates entails that the changes are always more favourable for the low-educated agents (lower displacement, higher re-employment), than for the better educated ones (higher displacement, lower re-employment).

**Exogenous displacement** Is obtained by imposing $\lambda_1^u = 0$, and by setting $\lambda_0^u = \ln(0.946) = 0.056$ from the observed statistics. Panel A of Figure 13 confirms that this results in a fall (increase) in displacement for the low (high) education agents. The other results in Figure 13, as well as in column 2 of Table 3 both confirm a strong fall in the incentive to invest (-15.3%), which induces a corresponding fall in human capital. The disinvestment is particularly large for the low-education employed. Because re-employment remains endogenous, it falls accordingly, inducing unemployment increases. Note finally that the fall in income is less important (-7.3%) than that of investment, implying an increase in consumption, and a corresponding increase in welfare.

**Exogenous re-employment** Is obtained by imposing $\lambda_1^e = 0$, and by setting $\lambda_0^e = \ln(0.372) = 0.989$ from the observed statistics. Panel A of Figure 14 shows that this results in a increase (fall) in re-employment for the low (high) education agents. The other results in Figure 14, as well as in column 3 of Table 3 indicate that removing the capacity to hedge re-employment risks reduces incentives to invest (-16.6%), especially for the high-education unemployed. Since displacement remains endogenous, the fall in human capital induces increases in displacement, and consequently also in unemployment. Again the fall in income is less important (-8.1%), justifying a possible gain in consumption that overcomes the hedging loss; welfare consequently increases.
Exogenous displacement and re-employment  

Is obtained by imposing $\lambda_1^u, \lambda_1^e = 0$, and by setting $\lambda_0^u = 0.056$, and $\lambda_0^e = 0.989$ from the baseline statistics. Combining both elements results, unsurprisingly, in the most important changes, as can be inferred from Figure 15, as well as in column 4 of Table 3. The loss in the employment risks hedging capacity results in a large disinvestment (-21.4%) and corresponding drop in human capital. Unemployment, displacement and re-employment are (by construction) all constant. Welfare nonetheless improves as less resources are devoted to hedging.

Overall, our simulation results indicate that employment risks hedging accounts for about 22% of both the investment level, and the accumulated human capital stock. Removing the capacity to diversify displacement and re-employment hazards leads to a deterioration in the employment and income situation. However, it also frees up resources that can be used for consumption purposes. Consequently, consumption and increases and more than compensates the higher exposition to employment risks, justifying the increase in welfare. Clearly, if the consequence of higher exposition is removed altogether through public UI policies, then welfare increases even more.

4.2.2 Structural changes

A second comparative statics exercise identifies four potential changes in the primitives that could be consistent with the increase in human capital discussed earlier. The results are plotted in Figures 16–19, while the changes relative to the baseline calibration in the moments from the simulated output are reported in columns Alt. 1–Alt. 4 of Table 4.

Alt. 1 Increasing income spreads up to 2000  

As discussed earlier, the income premia of the more educated workers relative to the less educated ones increased steadily up to the early 2000’s (see Panel B, of Figure 3). We model this change by lowering the fixed employed income parameter $\beta_0^e$, and increasing the income sensitivity to human capital $\beta_1^e$ in (10). First, in Panel B of Figure 16, the employed income schedule is clearly rotated counter-clockwise, thereby increasing the income return incentive for human
capital accumulation. In Panels C, and D, the investment levels and shares are higher for both employed and unemployed, except when the education level for the latter are low, in which case the drop in income imposes a reduction of investment. Despite the higher marginal return on education, the important deterioration in base income results in welfare deterioration for both employed and unemployed agents in Panel F.

The simulated moments in Column Alt. 1 of Table 4 confirms our findings. Both the unemployment and displacement rates fall, whereas the increase in re-employment is more important. The improvement in employment risks can be traced to the important increase in investment (+42.1%) which results in large increases in human capital (+41.8%) and income (+28%). Despite this, welfare falls (-8.6%) due to the important fall in disposable income $Y - I$.

**Alt. 2 Deterioration in UI net replacement rates after 2000** We saw that the net replacement rates in unemployment insurance regimes fell after 2000, especially for the higher income, and therefore more educated (see Figure 4). We model this change by lowering the unemployed income sensitivity to human capital parameter $\beta_u$ in (10). As seen in Panel B of Figure 17, this results in a downward shift of the unemployment income profile that is more important for the high $H$ agents. Since the income loss under unemployment is now more important, the income return motive for human capital acquisition increases, and Panels C, and D indicate that investment levels and shares increase for both types of agents, especially for the unemployed. This feature highlights the moral hazard inefficiency when self-insurance is allowed; private hedging through human capital increases when publicly-provided insurance conditions become unfavorable. Since this substitution is costly to the agent, Panel F shows that the unemployment income loss lowers welfare, especially for the unemployed.

Column Alt. 2 of Table 4 confirms that the net effects on employment risks are modest. Indeed, the optimal response in self-insurance offsets the deterioration in UI benefits with more investment (+2.4%) and human capital (+2.4%), such that unemployment,
displacement and re-employment, as well as income remain virtually unchanged. Again, this costly substitution towards more self-insurance when public coverage diminishes lowers welfare.

**Alt. 3 Falling re-employment after 2000** Figure 6 shows that re-employment rates fell after 2000, while Panel B of Figure 7 shows that such shifts tend to be more severe for the lower education levels. These elements are captured by lowering the constant parameter $\lambda_0^e$ in the re-employment intensity function (9). In Panel A of Figure 18, lower re-employment is more important for the low $H$. Since expected unemployment duration increases, this creates a risk hedging motivation for additional education, and investment levels and shares increase in Panels C and D, especially for the less educated unemployed agents. More investment and additional employment risks are unambiguously welfare reducing in Panel F.

Indeed, Column Alt. 3 of Table 4 indicates that the increase in investment and human capital (+7.9%) is important, but not enough to offset the deterioration in the returns to hedging; the re-employment probability falls (-1.3%), whereas unemployment and displacement are not affected. It follows that welfare drops (-7.5%), despite the rise in income (+3.6%).

**Alt. 4 Increasing displacement after 2000** Figure 6 also shows that displacement rates increased after 2000, while Panel A of Figure 7 indicates that these increases were more severe for the less educated. We incorporate such effects by increasing the human capital sensitivity $\lambda_1^u$ in the unemployment intensity function (9). This results in more acute displacement for all, especially for the lower levels of human capital in Panel A of Figure 19. Panels C, and D show that, contrary to previous cases, the investment levels and shares are adjusted differently across employment statuses. Indeed, whereas the employed do not change their investment, the unemployed agents lower both levels and shares, especially at low education levels. This reduction in investment expenditures can be explained by the fall of the human capital’s hedging capacity against displacement.
risk. It is also apparent in Column Alt. 4 of Table 4 which highlights the deterioration in employment risks, as well as the fall in both investment, human capital (-1.1% each) and income (-2.7%); unsurprisingly, welfare is negatively affected.

Overall, the simulated levels of human capital as well as the investment levels and shares in Table 4 increase for three of the four comparative statics scenarios. Put differently, the model predicts that increasing income spreads for the more educated prior to 2000, and/or deteriorating UI net replacement rates, as well as falling re-employment rates after 2000 would rationalize higher educational attainment in Figure 1, as well as increasing education demand in Figure 2. Conversely, the decline in the hedging ability to ward off displacement results in a lowering of the attractiveness of investing in human capital; both investment and stock fall.

5 Conclusion

Not everyone is equal in the face of employment risks. This paper has reviewed compelling evidence that the better educated not only earn higher incomes, but they also protect it better from adverse macro fluctuations. Indeed, both unconditional unemployment, and conditional displacement risks are much lower, whereas conditional re-employment is much higher for the better educated. We have argued that such hedging considerations should condition the demand for human capital. Surprisingly, they are mainly absent from existing literature. Search and Matching models specialize in diversifiable conditional risks yet abstract from dynamic human capital accumulation by households, whereas Human Capital models specialize in dynamic allocations, yet abstract from diversifiable conditional employment risks.

We have proposed a simple, and tractable human capital accumulation model that bridges this gap by allowing conditional employment risks to supplement the usual income premia motivation for the demand for education. This model was solved numerically and shown to replicate a number of empirical regularities, such as observed unemployment,
displacement and re-employment rates, human capital expenditures share of income, unemployment stigma, income scarring, cyclical properties of education demand, and moral hazard effects of UI coverage. Our simulation estimates evaluated the hedging motivation to 22% of the total investment and accumulated human capital levels. We next showed how structural changes affecting the returns to human capital, and identified in the data could generate the strong rise in educational expenditures and attainment that is observed in most countries.

Adopting such a simple setup obviously comes at a price. The first drawback is that we resort to a partial, rather than a general equilibrium analysis. We have followed the agent’s perspective in taking the income and hazard functions as given. However, these are endogenous objects that should be solved in equilibrium, as is done under SM frameworks. Put differently, we have focused exclusively on the supply side of the labour market equation. It remains to be shown that our functional forms for the returns to education are consistent with a fully-fledged demand side. Despite this limitation, we nonetheless feel that our results are sufficiently promising to warrant future effort towards that aim.

Second, our solution method is numerical rather than analytical and therefore remains tributary to a specific calibration. Simpler parametrizations might be able to yield closed forms, although the endogeneity of discounting under the Poisson assumption makes this highly hypothetical. Otherwise, a full-fledged estimation (e.g. based on Simulated Moments) might improve upon our simple calibration, and allow for more thorough hypothesis testing. Finally, we have not fully explored the normative implications of our results. As mentioned earlier, allowing for self-insurance affects the optimality and design of public intervention such as UI and/or education programs. Hopefully, future research could fruitfully be applied to these issues, relying on the insight provided by this type of models.
References


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A Figures

A.1 Data

Figure 1: Educational attainment

Notes: In % of US population aged 25y and over. Data from Current Population Survey. Legend: Less than high school (−); High school (+); Some college (−−−); Bachelor or more (+).
Figure 2: Education expenditures
A. Education expenditures shares, real prices

B. Cyclical components (% dev. from trend)

Notes: Data from Bureau Economic Analysis. Legend: Education expenditures shares ($C_{educ}/C$, —, LHS); Education real prices ($P_{educ}/P$, —, RHS). Panel B: HP-filtered log data.
Figure 3: Weekly earnings

A. Real weekly earnings

B. Relative to high school

Notes: Data from Current Population Survey. Median weekly earnings in real (base 1982-84) $. Legend: Less than high school (−); High school (◦); Some college (−·−); Bachelor or more (+).
Figure 4: UI net replacement rates

Notes: Data from OECD (2015), corresponding to US. Initial unemployment period. Family with 3 children, single earner. In percentage of pre-displacement earnings. Legend: 67% of AW (—); 100% of AW (—); 150% of AW (—).
Figure 5: Unemployment rates by education levels

A. Unemployment rates

B. Relative to high school

Notes: Data from Current Population Survey. Legend: Less than high school (—); High school (—); Some college (—); Bachelor or more (—).
Notes: Data from Labor Force Statistics from the Current Population Survey. Displacement (in blue, left-hand scale) defined as migration from Employed to Unemployed, divided by total employed. Re-employment (in red, right-hand scale) defined by migration from Unemployed to Employed, divided by total unemployed.
Figure 7: Conditional risks

A. Displacement  

B. Re-employment  

C. Pre-displ. income  

D. Scarring  

Notes: Data from Displaced Workers Survey. Legend: 1994 (—); 2000 (—); 2010 (—). A. Displacement $P[u_1 | e_0, H_0]$; B. Re-employment $P[e_1 | u_0, H_0]$; C. Pre-displacement income $[Y_0 | e_0, H_0]$; C. Scarring $%[Y_1 - Y_{-1} | e_1, u_0, e_{-1}]$.  

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A.2 Baseline results

Figure 8: Intensities
Figure 9: Baseline results

A. Employment risks

B. Income

C. Invest. levels

D. Invest. share

E. Growth

F. Value
Figure 10: Endogenous stigma

A. Growth

B. Continuing and re-employment
Figure 11: Endogenous scarring

A. Growth

B. Income
Figure 12: Endogenous cyclicality

A. Growth

B. Investment shares
A.3 Comparative statics

Figure 13: Exogenous displacement

A. Diffs. empl. risks
B. Diffs. income

C. Diffs. invest. levels
D. Diffs. invest. share
E. Diffs. growth
F. Diffs. value

Notes: Alternative parametrization obtained by $\lambda_1^u = 0, \lambda_0^u = 0.058$ in (9). Plots correspond to percentage changes in employed (blue), and unemployed (red) variables, relative to baseline parametrization.
Figure 14: Exogenous re-employment

A. Diffs. empl. risks

B. Diffs. income

C. Diffs. invest. levels

D. Diffs. invest. share

E. Diffs. growth

F. Diffs. value

Notes: Alternative parametrization obtained by $\lambda^e_1 = 0, \lambda^e_0 = 0.942$ in (9). Plots correspond to percentage changes in employed (blue), and unemployed (red) variables, relative to baseline parametrization.
Figure 15: Exogenous displ. and re-empl.

A. Diffs. empl. risks

B. Diffs. income

C. Diffs. invest. levels

D. Diffs. invest. share

E. Diffs. growth

F. Diffs. value

Notes: Alternative parametrization obtained by $\lambda^u_1 = 0, \lambda^u_0 = 0.058$, as well as $\lambda^e_1 = 0, \lambda^e_0 = 0.942$ in (9). Plots correspond to percentage changes in employed (blue), and unemployed (red) variables, relative to baseline parametrization.
Figure 16: Alt. 1, Increasing income spreads

A. Diffs. empl. risks

B. Diffs. income

C. Diffs. invest. levels

D. Diffs. invest. share

E. Diffs. growth

F. Diffs. value

Notes: Alternative parametrization: \( Y^e(H_-) \downarrow, Y^e(H_+) \uparrow \), obtained by \( \beta_0^e \downarrow, \beta_1^e \uparrow \) in (10). Plots correspond to percentage changes in employed (blue), and unemployed (red) variables, relative to baseline parametrization.
Figure 17: Alt. 2, Deteriorating unemployment revenues
A. Diffs. empl. risks

B. Diffs. income

Notes: Alternative parametrization: $Y^u(H_-) \downarrow, Y^u(H_+) \downarrow$, obtained by $\beta^u \downarrow$ in (10).
Plots correspond to percentage changes in employed (blue), and unemployed (red) variables, relative to baseline parametrization.
Figure 18: Alt. 3, Falling re-employment

A. Diffs. empl. risks

B. Diffs. income

C. Diffs. invest. levels

D. Diffs. invest. share

E. Diffs. growth

F. Diffs. value

Notes: Alternative parametrization: $\lambda^u(H_-) \uparrow, \lambda^u(H_+) \uparrow$, obtained by $\lambda^u_1 \uparrow$ in (9). Plots correspond to percentage changes in employed (blue), and unemployed (red) variables, relative to baseline parametrization.
Figure 19: Alt. 4, Increasing displacement

A. Diffs. empl. risks

B. Diffs. income

C. Diffs. invest. levels

D. Diffs. invest. share

E. Diffs. growth

F. Diffs. value

Notes: Alternative parametrization: $\lambda^e(H^-) \downarrow, \lambda^e(H^+) \downarrow$, obtained by $\lambda^e_0 \downarrow$ in (9). Plots correspond to percentage changes in employed (blue), and unemployed (red) variables, relative to baseline parametrization.
B Tables

Table 1: Calibrated parameters

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Notes: Parameters $\alpha, \delta$ for investment function in (1), where we have set $A = 1$; discount rate $\rho$ in (5); employment intensity parameters $\lambda^i, \xi^i$ in (9); income function parameters $\beta^i$ in (10); dimension of the state space $H \in (a,b)$, with number of Chebyshev nodes $M$, and shape-preserving nodes $N$.

Table 2: Simulated model: Matching the moments

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Notes: Data are $^1$: from BLS, Current Population Survey, and Displaced Workers Summary, year 2013; $^2$ from UN Development Program, year 2012. Baseline results from calibration in Table 1. Simulated results from simulation over 10’000 individuals over 150-year period, with 50-year burn-in period.
Table 3: Simulated results: Gauging the hedging

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Notes: Baseline results from calibration in Table 1. Simulated results from simulation over 10’000 individuals over 150-year period, with 50-year burn-in period. Results in columns 2–4 correspond to percentage deviation from baseline simulated results.

Table 4: Simulated results: Alternatives

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</tbody>
</table>

Notes: Baseline results from calibration in Table 1. Alternative parametrization are Alt. 1 (Fig. 16): Increasing income spreads up to 2000, Y^e(H_-) ↓, Y^e(H_+) ↑, obtained by β_0 ↓, β_1 ↑ in (10); Alt. 2 (Fig. 17): Deterioration in UI net replacement rates after 2000, Y^u(H_-) ↓, Y^u(H_+) ↓, obtained by β_0 ↓ in (10); Alt. 3 (Fig. 18): Falling re-employment after 2000, λ^u(H_-) ↑, λ^u(H_+) ↑, obtained by λ_1 ↑ in (9); Alt. 4 (Fig. 19): Increasing displacement after 2000, λ^e(H_-) ↓, λ^e(H_+) ↓, obtained by λ_0 ↓ in (9). Simulated results from simulation over 10’000 individuals over 150-year period, with 50-year burn-in period. Results in columns 2–5 correspond to percentage deviation from baseline simulated results.