Human-Capital Formation: the Importance of Endogenous Longevity

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Education and life expectancy move together

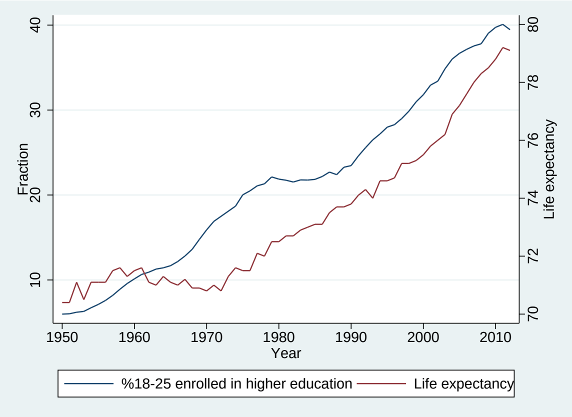

Figure: *Educational attainment and life expectancy among Dutch males.*

Education and life expectancy move together

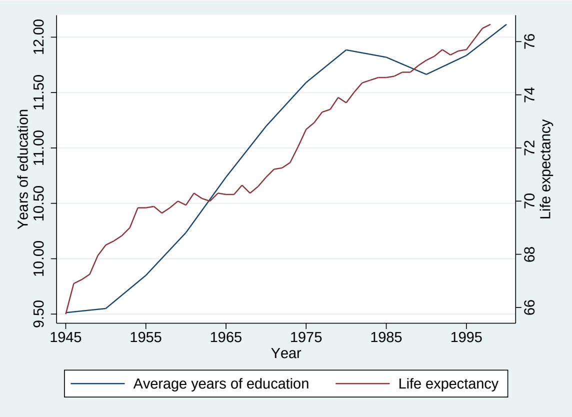

Figure: *Educational attainment and life expectancy, USA.*

Education and life expectancy move together

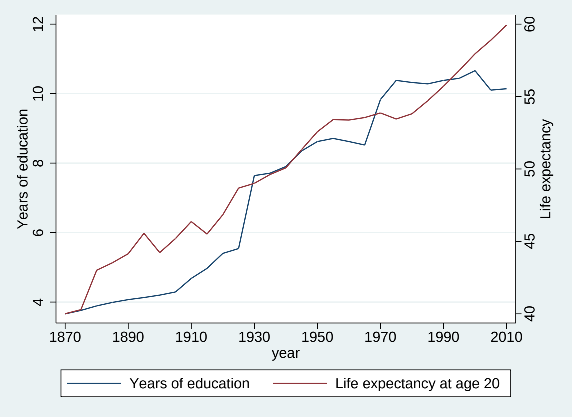

Figure: *Years of education and life expectancy at age 20 in Sweden.*

Are trends in wealth, education, health, longevity related?

- US' 20^{th} Century saw unprecedented increases in income, longevity, health, and educational attainment.
  - real per-capita income in 2000 was five to six times its level in 1900 (Goldin and Katz, 2009),
  - life expectancy at birth increased from 46 to 74 years for white men (CDC), and
  - schooling rose from 7 to 13 years (Bleakley et al. 2014).
- Similarly impressive advances took place in other developed and increasingly also in developing nations (Deaton, 2013).
- Are these trends in wealth, education, health and longevity related? And do they reflect causal mechanisms?

What explains observed heterogeneity?

- Longevity gains do not always translate into gains in education or in economic growth.[1]
- Despite a very strong association between them, whether education causes health and longevity is widely debated.
  - effects of education exist in some contexts but not others, depend on age, gender, returns to education, quality and type of education (Galama et al. 2018; Kaestner et al 2020).
- "Skills beget skills" through self-productivity and dynamic complementarity (Cunha and Heckman 2007)
  - but their role appears to be context-specific.[2]
- What explains the substantial heterogeneity in causal effects, self/cross-productivity and dynamic complementarities?

[1] Acemoglu and Johnson, 2007; Hazan, 2009; Cervellati and Sunde, 2011
[2] Almond and Mazumder, 2013; Malamud et al., 2016; Almond et al., 2018

Human Capital theory

- Human Capital theory[3] predicts an effect of life expectancy on educational attainment
  - longer life increases the period over which returns to investing in human capital can be accrued
  - empirical evidence for this mechanism[4]

[3] Schultz, 1961; Becker, 1964; Ben-Porath, 1967; Mincer, 1974

[4] Jayachandran and Lleras-Muney, 2009; Fortson, 2011; Oster et al. 2013

Human Capital theory

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  - longer life increases the period over which returns to investing in human capital can be accrued
  - empirical evidence for this mechanism[4]

- However, the theory has two shortcomings
  - life expectancy is fixed and exogenously given
  - health is distinct from human capital (skill)
    - a) investments should decrease towards the end of life
    - b) fits well for skill, but not for health

[3] Schultz, 1961; Becker, 1964; Ben-Porath, 1967; Mincer, 1974

[4] Jayachandran and Lleras-Muney, 2009; Fortson, 2011; Oster et al. 2013

Health Capital theory

- Health Capital theory (Grossman, 1972) predicts an effect of educational attainment on health
  - also empirical evidence for this mechanism[5]
- However, here both education and life expectancy are fixed and exogenously given
  - Ehrlich and Chuma (1990) incorporated endogenous longevity

[5] Lleras-Muney, 2005; Conti et al. 2010; Van Kippersluis et al. 2011; Galama et al. 2018; Karlsson et al. 2019

Human Capital and Health Capital

- Human capital theory emphasizes the effect of life expectancy on educational attainment
- Health capital theory emphasizes the effect of education on health and life expectancy
- Both theories provide only partial, and often competing, explanations for the association between education, health, and life expectancy

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- Both theories provide only partial, and often competing, explanations for the association between education, health, and life expectancy
- "*We lack comprehensive theoretical models in which the stocks of health and knowledge are determined simultaneously. The rich empirical literature (...) underscores the potential payoffs to this undertaking*" (Grossman 2000)

In this paper, we

1. Develop a simple theory of joint investment in skill capital, health capital, and longevity (that can be analytically solved)
   - investments in health consist of, e.g., medical care and exercise
   - investments in skill consist of, e.g., education and training
2. Conduct comparative dynamic analyses to derive predictions from the theory
3. Calibrate a more general model to further assess the theoretical predictions

Main results

1. *Endogenous* gains in longevity are a **necessary** condition for
   - persistent *causal* relations between wealth, skill and health.
   - persistent self-productivity and dynamic complementarity in skill and health.

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1. *Endogenous* gains in longevity are a **necessary** condition for
   - persistent *causal* relations between wealth, skill and health.
   - persistent self-productivity and dynamic complementarity in skill and health.

2. However, endogenous gains in longevity are not a **sufficient** condition.
   - institutions, biology, medical technology, the quality of schooling, and the returns to investment also need to be conducive to skill formation and health.

Intuition

Consider the effect of greater health $\delta H_{t'}$ on later-life skill $\theta(t)$

$$\frac{\partial \theta(t)}{\partial H_{t'}} = \left.\frac{\partial \theta(t)}{\partial H_{t'}}\right|_{T} + \left.\frac{\partial \theta(t)}{\partial T}\right|_{H_{t'}} \frac{\partial T}{\partial H_{t'}}.$$

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- Causal effects fade out if longevity T is fixed
  - Ben-Porath mechanism shut down
  - any health gain has to depleted at the fixed time of death
- A persistent causal effect of health on skill necessarily requires endogenous longevity (**necessary condition**)

Intuition (cont'd)

$$\frac{\partial \theta(t)}{\partial H_{t'}} = \left.\frac{\partial \theta(t)}{\partial H_{t'}}\right|_{T} + \left.\frac{\partial \theta(t)}{\partial T}\right|_{H_{t'}} \frac{\partial T}{\partial H_{t'}}.$$

- $\left.\frac{\partial \theta(t)}{\partial T}\right|_{H_{t'}}$ is influenced by institutions & technology.

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- $\left.\frac{\partial \theta(t)}{\partial T}\right|_{H_{t'}}$ is influenced by institutions & technology. Small
  - if skill-capital investment is unproductive (e.g., low quality teachers, children infected with worms, or malaria),
  - if cost of skill-capital investment is high (e.g., high tuition, long distance to schools, crops that need to be harvested),
  - if institutional environment generates only limited demand for skill (e.g., corruption, limited technological capabilities, etc.),

  $\Rightarrow$ effects of health on later-life skill small (same for other stocks).
- Hence, endogenous longevity is **not a sufficient condition**

Theoretical formulation

Individuals maximize the discounted lifetime utility function

$$\mathbb{U} = \max \int_0^T U[.]e^{-\beta t}dt$$

where utility $U[\cdot]$ is derived from consumption $X_C(t)$, leisure $L(t)$, skill $\theta(t)$, and health $H(t)$:

$$U(t) = \frac{1}{1-\rho}\left(X_C(t)^{\zeta}\left\{L(t)[\theta(t)+H(t)]\right\}^{1-\zeta}\right)^{1-\rho},$$

and individuals die at the optimal age T when health reaches a minimum level $H(T) = H_{\min}$

The utility function is maximized subject to the following dynamic constraints for skill capital $\theta(t)$ and health capital $H(t)$

$$\begin{aligned}\frac{\partial \theta}{\partial t} &= f_\theta\left[I_\theta(t)\right] - d_\theta(t)\theta(t),\\ \frac{\partial H}{\partial t} &= f_H\left[I_H(t)\right] - d_H(t)H(t).\end{aligned}$$

where investment I is produced using goods X and time inputs τ, and we assume Cobb-Douglas functional forms for the production functions:

$$f_\theta = \psi_\theta(t)\left\{\tau_\theta(t)\left[\theta(t) + H(t)\right]\right\}^{\alpha_\theta} X_\theta(t)^{\beta_\theta},$$
$$f_H = \psi_H(t)\left\{\tau_H(t)\left[\theta(t) + H(t)\right]\right\}^{\alpha_H} X_H(t)^{\beta_H}.$$

Further, individuals face a budget constraint regarding assets $A(t)$:

$$\frac{\partial A}{\partial t} = rA(t) + Y(t) - p_C(t)X_C(t) - p_\theta(t)X_\theta(t) - p_H(t)X_H(t).$$

where income $Y(t)$ is given by

$$Y(t) = [\theta(t) + H(t)] * \tau_w(t), \tag{1}$$

and the time spent working $\tau_w(t)$ is defined by the time constraint

$$\tau_w(t) = 1 - \tau_\theta(t) - \tau_H(t) - L(t).$$

The Hamiltonian is given by

$$\Im \quad = \quad U[\cdot]e^{-\beta t} + q_\theta(t)\frac{\partial \theta}{\partial t} + q_H(t)\frac{\partial H}{\partial t} + q_A(t)\frac{\partial A}{\partial t},$$

where $q_\theta(t)$ is the marginal value of skill:

$$q_\theta(t) = \frac{\partial}{\partial \theta(t)} \int_t^{T^*} U(*)e^{-\beta s} ds,$$

$q_H(t)$ is the marginal value of health, and $q_A(t)$ of assets.

We have the initial conditions $\theta(0) = \theta_0$, $H(0) = H_0$, $A(0) = A_0$, and the terminal conditions $\theta(T) =$ free, $H(T) = H_{\min}$, and $A(T) = A_T$.

First order conditions

The convenient functional form assumptions enable us to

- Obtain analytical expressions ▸ Analytical expression

The convenient functional form assumptions enable us to

- Obtain analytical expressions Analytical expression
- Conduct comparative dynamic analyses to derive predictions
  - For example, how does the life cycle path of skills (education, training) vary with initial health: $\partial\theta(t)/\partial H_0$?

Comparative dynamic results

Comparative dynamics can be separated into two components

$$\frac{\partial g(t)}{\partial Z_0} = \underbrace{\left.\frac{\partial g(t)}{\partial Z_0}\right|_T}_{\text{Variation for fixed } T} + \underbrace{\left.\frac{\partial g(t)}{\partial T}\right|_{Z_0} \frac{\partial T}{\partial Z_0}}_{\text{Variation due to change in } T}$$

	δA_0		$\delta \theta_0$		δH_0	
Function $g(t)$	T fixed	T free	T fixed	T free	T fixed	T free
$\theta(t)$	0	> 0	> 0	> 0	0	> 0
$I_\theta(t)$	0	> 0	0	> 0	0	> 0
$H(t)$	0	> 0	0	> 0	≥ 0	> 0
$I_H(t)$	0	> 0	0	> 0	< 0	+/-
$A(t)$	≥ 0	+/-	+/-	+/-	+/-	+/-
$X_C(t)$	> 0	$> 0^\dagger$	> 0	$> 0^\dagger$	> 0	$> 0^\dagger$
$L(t)$	> 0	$> 0^\dagger$	> 0	$> 0^\dagger$	> 0	$> 0^\dagger$
T	n/a	> 0	n/a	> 0	n/a	> 0

Endogenous longevity as a necessary condition

$$\frac{\partial g(t)}{\partial Z_0} = \underbrace{\left.\frac{\partial g(t)}{\partial Z_0}\right|_T}_{\text{Variation for fixed } T} + \underbrace{\left.\frac{\partial g(t)}{\partial T}\right|_{Z_0} \frac{\partial T}{\partial Z_0}}_{\text{Variation due to change in } T}$$

Absent the ability to extend length-of-life, there is no effect of initial conditions on skill and health: $\partial g(t)/\partial Z_0|_T \sim 0$

- Any additional investment in health (and skill) would have to be compensated by eventual lower investment since life is fixed
- The additional wealth is used to finance additional consumption and leisure (see also Heckman, 1976)

Endogenous longevity gains enable causal effects

$$\frac{\partial g(t)}{\partial Z_0} = \underbrace{\left.\frac{\partial g(t)}{\partial Z_0}\right|_T}_{\text{Variation for fixed } T} + \underbrace{\left.\frac{\partial g(t)}{\partial T}\right|_{Z_0} \frac{\partial T}{\partial Z_0}}_{\text{Variation due to change in } T}$$

- With ability to extend life, wealthy, skilled, and healthy individuals live longer (Ehrlich and Chuma, 1990; Hall and Jones, 2007): $\partial T / \partial Z_0 > 0$
- The resulting longevity gains generate further investments: $\partial g(t)/\partial T|_{Z_0} > 0$

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- The resulting longevity gains generate further investments: $\partial g(t)/\partial T|_{Z_0} > 0$
- **Implication**: Endogenous longevity gains are a necessary condition for causal effects of endowments on later-life human capital

Self-productivity and dynamic complementarity

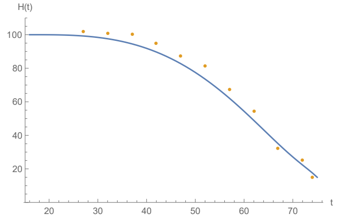
- So far the comparative dynamics were in terms of endowments, i.e. θ_0 and H_0
- Yet, we can restart the problem at any time t', taking $\theta(t')$, and $H(t')$, as the new initial conditions
- Results can also shed light on two defining features of human capital investments:
  - self-productivity, where skills produced at one stage augment skills at later stages
  - dynamic complementarity, where skills produced at one stage raise the productivity of investment at later stages

$$\left.\frac{\partial^2 \theta(t)}{\partial \theta_{t'} \partial I_\theta(t)}\right|_T \sim 0$$

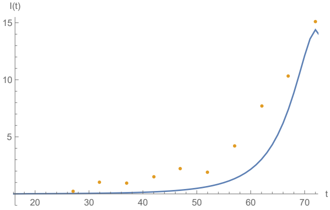
Calibrated model

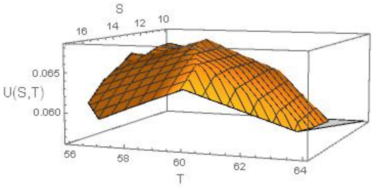
- Discrete time, starting at age 16
- Years of schooling instead of the stock of skill capital
- Less restrictive functional forms ▸ Functional forms
  - utility
  - health production
  - earnings
- Fix a large number of parameters from the literature ▸ Parameters
- Use the Panel Study of Income Dynamics (PSID) to estimate Mincer earnings equation
- Calibrate the remaining 5 parameters to match average health, health investment, and the association between life expectancy and years of schooling in the United States (2000)

Model fit



1. Health.
2. Health investment.
3. Schooling and life expectancy.





Discussion

- We developed an explicit theory of joint investments in financial, skill, and health capital, and longevity that can be solved analytically
- We next simulated a more realistic model that we calibrated
- By explicitly modeling joint investment in both skill and in health, the model defines and highlights the similarities and differences in the nature of skill and health
- One crucial aspect of health makes it distinct from skill, which is that health extends life (Ehrlich and Chuma 1990)

Discussion (continued)

- In this paper we explored the importance of endogenous life extension, i.e. the ability of individuals to extend life through investments (e.g., medical care, health behaviors).
- We provided evidence that endogenous longevity acts as a fundamental driver of human-capital formation, enabling
  - (i) causal effects of past stocks of wealth, skill and health on later-life wealth, skill and health, and
  - (ii) self-productivity and dynamic complementarity processes
- Without the ability of individuals to extend their lives, such causal effects and such self-productivity and dynamic complementarity processes are virtually non existent

Discussion

THANK YOU!

First-order condition skill capital investment

$$q_{\theta/a}(t) = \pi_\theta(t)$$

where

$$q_{\theta/a}(t) = \int_t^T e^{-\int_t^s [d_\theta[x]+r]dx} \left(\frac{\partial Y}{\partial \theta}\right) ds.$$

and

$$\pi_\theta(t) \equiv \frac{p_\theta(t)}{\partial f_\theta / \partial X_\theta} = \frac{w[\theta(t), H(t)]}{\partial f_\theta / \partial \tau_\theta}.$$

Decision to invest in skill today weighs the current monetary price and opportunity cost with its future benefits (from t to T): the discounted value of increased earnings.

First-order condition health capital investment

$$q_{h/a}(t) = \pi_H(t)$$

where

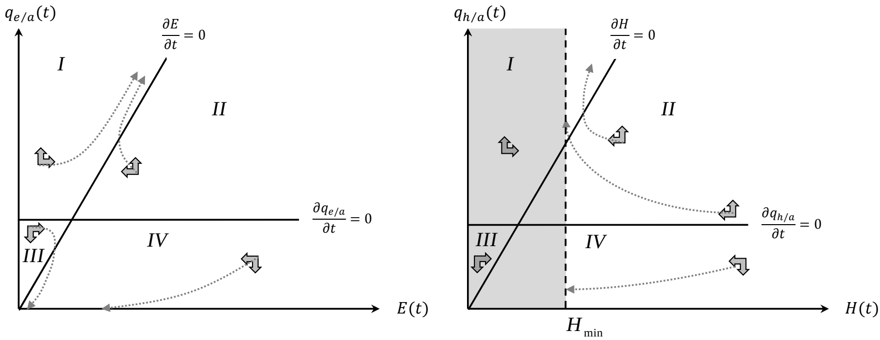
$$q_{h/a}(t) = q_{h/a}(T)e^{-\int_t^T [d_H(x)+r]dx} + \int_t^T e^{-\int_t^s [d_H[x]+r]dx} \left(\frac{\partial Y}{\partial H} + \frac{\lambda_{H_{\min}}(s)}{q_A(s)} \right) ds$$

and

$$\pi_H(t) \equiv \frac{p_H(t)}{\partial f_H / \partial X_H} = \frac{w[\theta(t), H(t)]}{\partial f_H / \partial \tau_H}.$$

Decision to invest in health today weighs the current monetary price and opportunity cost with its future benefits (from t to T): increased earnings and a longer life

Back


$q_{e/a}(t)$
$\frac{\partial E}{\partial t} = 0$
I
II
$\frac{\partial q_{e/a}}{\partial t} = 0$
III
IV
$E(t)$
$q_{h/a}(t)$
$\frac{\partial H}{\partial t} = 0$
I
II
$\frac{\partial q_{h/a}}{\partial t} = 0$
III
IV
$H(t)$
H_{min}

Example analytical solution for $\theta(t)$

$$\theta(t) = \theta_0 e^{-\int_0^t d_\theta(x)dx} + \int_0^t \mu_\theta(s) q_{\theta/a}(s)^{\frac{\gamma_\theta}{1-\gamma_\theta}} e^{-\int_s^t d_\theta(x)dx} ds$$

$$\mu_\theta(t) \equiv \left[\frac{\alpha_\theta^{\alpha_\theta} \beta_\theta^{\beta_\theta} \psi_\theta(t)}{p_\theta(t)^{\beta_\theta}}\right]^{\frac{1}{1-\gamma_\theta}}$$

$$q_{\theta/a}(t) = \int_t^T e^{-\int_t^s [d_\theta[x]+r]dx} \left(\frac{\partial Y}{\partial \theta}\right) ds.$$

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Analytical solution for $\partial\theta(t)/\partial T$

$$\left.\frac{\partial\theta(t)}{\partial T}\right|_{Z_0} = \frac{\gamma_\theta}{1-\gamma_\theta}\int_0^t \mu_\theta(s) q_{\theta/a}(s)^{\frac{2\gamma_\theta - 1}{1-\gamma_\theta}} \left.\frac{\partial q_{\theta/a}(s)}{\partial T}\right|_{Z_0} e^{-\int_s^t d_\theta(x)dx} ds$$

$$\mu_\theta(t) \equiv \left[\frac{\alpha_\theta^{\alpha_\theta}\beta_\theta^{\beta_\theta}\psi_\theta(t)}{p_\theta(t)^{\beta_\theta}}\right]^{\frac{1}{1-\gamma_\theta}}$$

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Calibrated model

Individuals maximize the discrete-time life-time utility function

$$\sum_{t=0}^{S-1}\left[\frac{U(C_t,H_t)}{(1+\beta)^t}-p^S\right]+\sum_{t=S}^{T-1}\frac{U(C_t,H_t)}{(1+\beta)^t}$$

where individuals live for T endogenous periods, S is the endogenous number of years of schooling, and p^S is the psychic cost of schooling. We follow Scholz and Seshadri (2016), using

$$U[C_t,H_t]=\frac{\mu_U}{1-\rho}\left[\lambda C_t^{\zeta}+(1-\lambda)H_t^{\zeta}\right]^{\frac{1-\rho}{\zeta}}+B$$

where μ_U is a scale parameter, ρ is the coefficient of relative risk aversion, $\frac{1}{1-\zeta}$ measures the elasticity of substitution, λ the relative importance of consumption versus health, B is a constant to ensure positive utility.

Calibrated model (cont'd)

The utility function is maximized subject to

$$
\begin{aligned}
H_{t+1} - H_t &= \mu_I(t,S) m_t^{\alpha} - d_t H_t^{\nu}, \quad 0 < t < T-1 \\
A_{t+1} - A_t &= rA_t - p_C C_t - p_m m_t + c_t^S, \quad 0 < t < S-1 \\
A_{t+1} - A_t &= rA_t + \gamma_w w_t(S, t-S) H(t)^{\gamma_H} - p_C C_t - p_m m_t, S < t < T-1
\end{aligned}
$$

where $d_t = at + bt^2$, and

$$
\begin{aligned}
\mu_I(t,S) &= \kappa t, & 0 < t < S-1 \\
\mu_I(t,S) &= \kappa S, & S < t < T-1
\end{aligned}
$$

We follow Scholz and Seshadri (2016), specifying the earnings function as

$$
Y_t = \gamma_w w_t H_t^{\gamma_H}
$$

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Parameters for calibration

Parameter	Description	Value
Parameters taken from the literature		
α	Effectiveness of health investment	0.75
r	Interest rate	0.03
β	Time preference rate	0.03
ρ	Coefficient of relative risk aversion	3
ζ	Elasticity of substitution	-3.6
λ	Utility share of consumption vs health	0.7
ν	Dependency of depreciation on health	0.3
H_0	Initial health	100
H_T	Terminal health	15
A_0, A_T	Assets	0
Normalized parameters		
μ_C	Efficiency of consumption	1
p_m	Price of medical care	1
p_c	Price of consumption	1

Parameters for calibration (cont'd)

Parameter	Description	Value
Estimated parameters		
γ_w	Earnings parameter 1	6.8482
γ_H	Earnings parameter 2	0.0489
π_0	Mincer equation constant	2.0407
π_1	Mincer equation returns to education	0.0932
π_2	Mincer equation experience	0.0068
π_3	Mincer equation experience squared	-0.00018
Calibrated parameters		
κ	Efficiency of health investment	0.015
a	Deterioration rate intercept	0.00069
b	Deterioration rate slope	0.00046
p^S	Psychic cost of schooling	0.005
B	Constant shifter of utility	0.002

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Longevity gains generate inequality

Figure: *Atkinson index for inequality in education versus inequality in life expectancy, unweighted (left) and weighted by population size (right). Country codes as used by World Bank. Source: United Nations*