Medical progress as a driver of (unequal) life cycle outcomes

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Motivation I: Life expectancy

- Large and increasing difference in life expectancy by SES
- Differences are exaggerated by increasing selectivity of lower ed. groups, but differences remain after adjusting for this

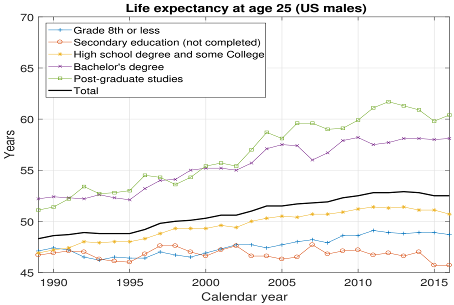

Figure 1: US male life expectancy at age 25, 1989–2016

Source: Authors' calculations based on CDC data.

Motivation II: Income

- The wage gap between males with post-college education and high school dropouts rose from 1979 through 2005

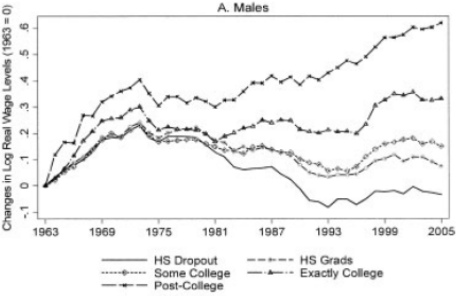

Figure 2: Trends in composition-adjusted real log weekly full-time wages by education, 1963–2005 (March CPS)
Source: Autor et al. (2008, REStat)

Introduction

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  - Productivity growth and medical progress as drivers of (i) development over time; (ii) inequality

Model I

- Individuals maximize their life-cycle utility

$$
\begin{aligned}
V(\mathbf{c}, \mathbf{l}, \mathbf{S}, E, R, T) = & \int_0^E e^{-\rho t} u(c(t), 0, \phi) S(t) dt \\
& + \int_E^R e^{-\rho t} u(c(t), l(t), 0) S(t) dt \\
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- subject to

dynamic state	depending on	impacting
survival	mortality	remaining life exp
health deficits	health care + initial defs	mortality + depr hum cap
human capital	education + health defs + learning ability	earnings
financial wealth	cons + health care + education	ditto

Model II

- Individual heterogeneity with respect to their endowment
  1. health deficits at birth (tantamount to frailty)
  2. learning ability
  3. disutility of attending school ϕ (tantamount to parental aversity to schooling and other access barriers)

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- Sequential solution of the model to obtain optimal
  1. laws of motion for consumption, labor and health care (over the life-cycle)
  2. retirement age
  3. longevity
  4. choice of schooling

Numerical analysis

- In the numerical analysis we

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3. Three targets: (i) evolution of life expectancy 1910–1970; (ii) health care spending share for the cohorts 1910–1930; (iii) Educational distribution for 1910 cohort: Primary=48%, secondary=43%, postsecondary=8% (Data from Edu20c.org)

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   - **two counterfactuals:** one without productivity growth, one without medical progress
5. **Note:** Medical progress has been calibrated such that medicine explains $< 50\%$ of the increase in life expectancy

Results: Lifecycle profiles I

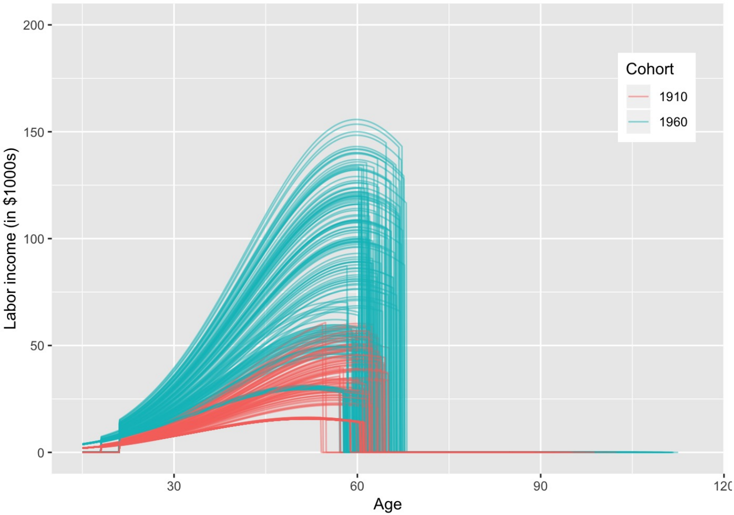


Figure 3: Labor Income: US birth cohorts 1910 (red) and 1960 (blue).

Results: Lifecycle profiles II

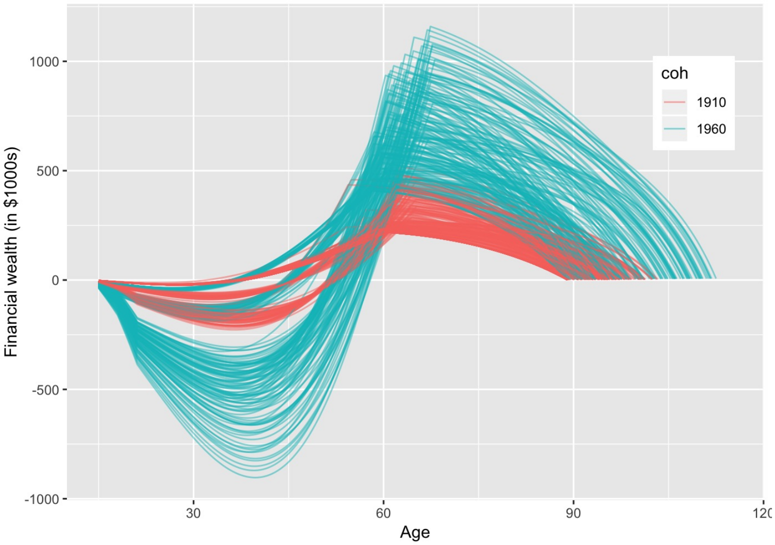
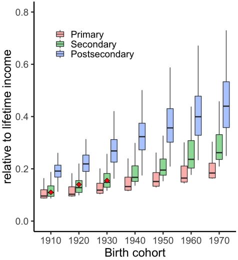


Figure 4: Assets: US birth cohorts 1910 (red) and 1960 (blue).

Results: Health care expenditure

* Health care spending increases over time both within and across educational groups

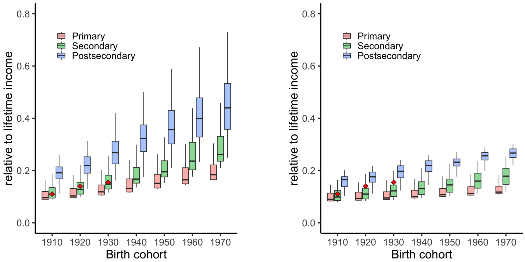


(a) Benchmark

Figure 5: Cohort health care spending share by educational attainment. Source: Authors' simulations and Hall and Jones (2007) (red diamonds).

Results: Health care expenditure

* Productivity growth raises the health care spending share (Hall and Jones, 2007; Fonseca et al, 2013; Frankovic and Kuhn, 2018)



(a) Benchmark

(b) No medical progress + productivity growth

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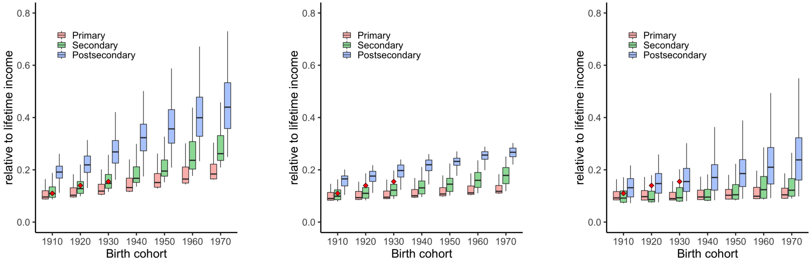
Results: Health care expenditure

* Medical progress as a similarly potent driver of health care spending (Fonseca et al, 2013; Frankovic and Kuhn, 2018)



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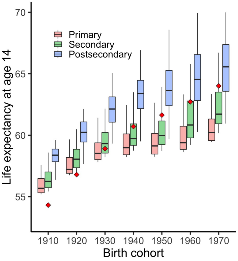
Results: Life expectancy

* Average LE increases faster for individuals with postsecondary education than for individuals with primary education

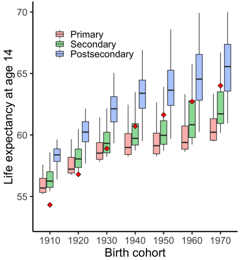


(a) Benchmark

Figure 6: Life expectancy at age 14 by educational attainment. Source: Authors' simulations and Bell et al. (1992) (red diamonds).

Results: Life expectancy

* Medical progress accounts for a sizeable share of the rise in average LE



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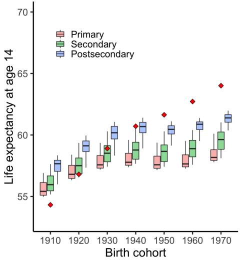

(b) No medical progress + productivity growth

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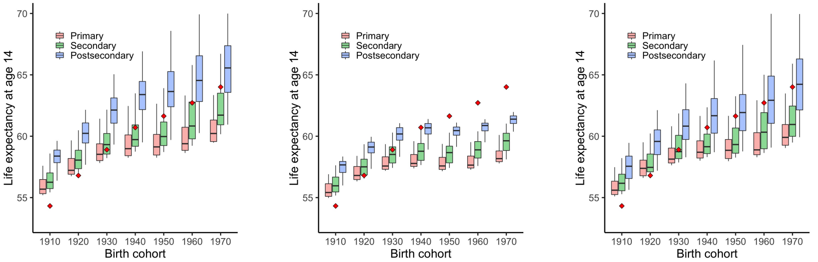
* Productivity growth leads to an increase in the price of health and dampens increase in life expectancy across education groups



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Results: Wellbeing in benchmark

- **Wellbeing measure:** Maximized life-cycle utility $V(\mathbf{c}^*, \mathbf{l}^*, \mathbf{S}^*, \mathbf{E}^*, \mathbf{R}^*, \mathbf{T}^*)$

Education		**Cohorts** 1910	1920	1930	1940	1950	1960	1970
Primary	mean	0,967	1,023	1,072	1,103	1,127	1,151	1,176
	std.dev	0,024	0,028	0,036	0,043	0,049	0,050	0,041
Secondary	mean	0,984	1,040	1,086	1,119	1,141	1,183	1,224
	std.dev	0,026	0,031	0,035	0,044	0,051	0,065	0,082
Tertiary	mean	1,050	1,111	1,180	1,237	1,275	1,333	1,406
	std.dev	0,027	0,040	0,056	0,070	0,099	0,134	0,180
Average	mean	**1,001**	**1,058**	**1,112**	**1,153**	**1,181**	**1,222**	**1,269**
	std.dev	**0,026**	**0,033**	**0,042**	**0,052**	**0,066**	**0,083**	**0,101**

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- ...within education group, in particular the tertiary (Selection!)

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No Medical Progress								
	mean	**0,988**	1,038	1,076	1,099	1,111	1,132	**1,157**
	std.dev	**0,021**	0,023	0,023	0,024	0,022	0,023	**0,022**
No Productivity Growth								
	mean	**0,921**	0,956	0,983	0,995	1,007	1,031	**1,059**
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Results: Role of medical progress and productivity growth

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- ...medical progress provides a much stronger boost to inequality

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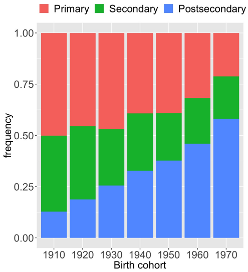
- Medical progress a much stronger propensity to widen disparities, presumably by triggering strong selection into education groups

Thank you!

This project has received funding from the Austrian National Bank (OeNB) under Grant no. 17647.

Results: Educational attainment

* Strong educational expansion implies strong selection effects

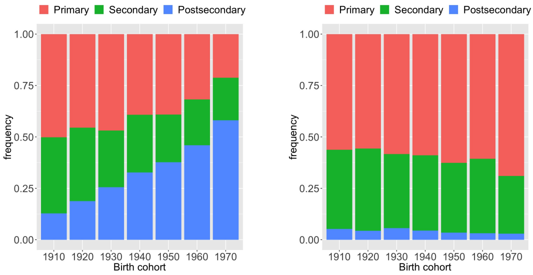


(a) Benchmark

Figure 9: Educational distribution: Birth cohorts 1910–1970. Source: Authors' simulations.

Results: Educational attainment

* A strong Ben-Porath effect: Absence of medical progress eliminates returns of education



(a) Benchmark

(b) No medical progress + productivity growth

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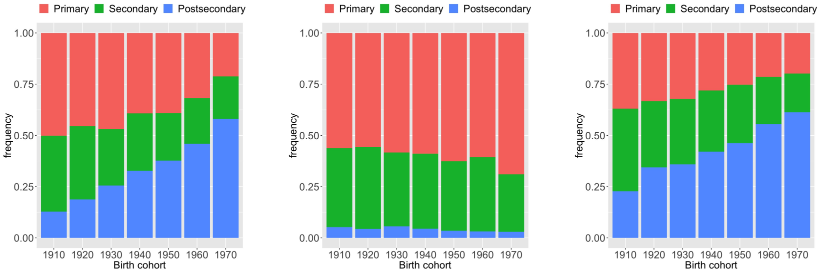
Results: Educational attainment

* Medical progress is key to explain the increase in education



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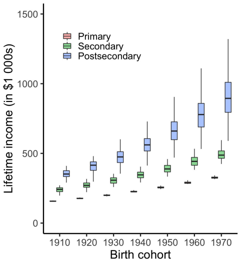
Results: Lifetime income

*

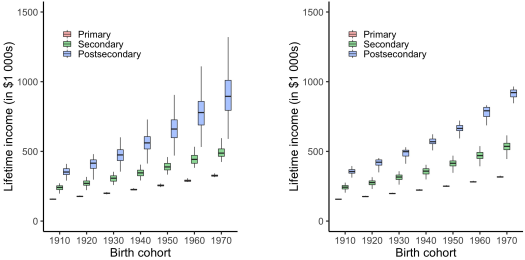


(a) Benchmark

Figure 10: Cohort lifetime labor income by educational attainment. Source: Authors' simulations.

Results: Lifetime income

* Case (b) The increase is due to productivity growth



(a) Benchmark

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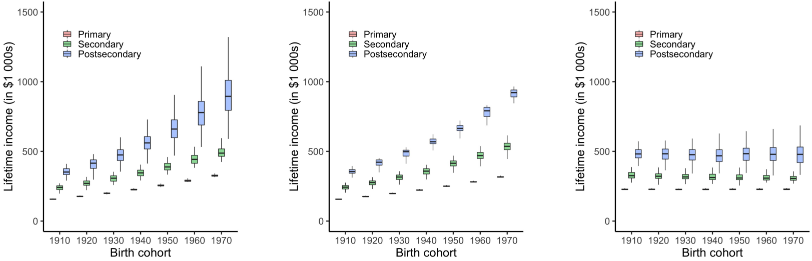
Figure 10: Cohort lifetime labor income by educational attainment. Source: Authors' simulations.

Results: Lifetime income

* Case (c) Flat incomes in the absence of productivity growth



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The individual

Survival and health deficit accumulation:

- Survival as a fourth state as in Kuhn et al. (2015), Schünemann et al. (2017) and Dragone and Strulik (2018)

$$\dot{S} = -\mu(D, z)S \text{ with } S(0, z) = 1, \tag{1}$$

where z denotes the birth cohort.

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where z denotes the birth cohort.

- Health deficits accumulation: Dalgaard and Strulik (2014)

$$\dot{D} = \beta_d(D - A(E)h^\eta - \gamma_d) \quad (2)$$

with $\dot{A}(E)/A(E) = g_h/(1 + \alpha_g t)$ (decreasing medical progress), $\eta \in (0, 1)$ returns to health care investment, $D(t) \leq \overline{D}$, $D(T) = \overline{D}$.

heterogeneous initial health deficits: $D(0) \sim \gamma_d + \mathbb{U}(\underline{\alpha_d}, \overline{\alpha_d})$

mortality modeling

The individual (cont'd)

- **Health-dependent human capital**:

$$\dot{H} = \begin{cases} \theta H^{\gamma} - \delta(D)H & \text{for } t \leq E, \\ -\delta(D)H & \text{for } t > E, \end{cases} \tag{3}$$

E length of schooling, θ learning ability level, $\delta(D) = \kappa D^2$ depreciation of human capital, and $\gamma \in (0, 1)$ return-to-scale of education

heterogeneous learning ability: $\theta \sim \mathbb{U}(\underline{\theta}, \overline{\theta})$

The individual (cont'd)

- **Assets accumulation**:

$$\dot{a} = \begin{cases} ra - c - p_h h - p_\mu \mu(D, z) - TU_z(E) & \text{for } 0 < t \leq E, \\ ra - c - p_h h - p_\mu \mu(D, z) + w_z(D, E|\theta)\ell & \text{for } E < t \leq R, \\ ra - c - p_h h - p_\mu \mu(D, z) & \text{for } R < t \leq T. \end{cases} \quad (4)$$

where $TU_z(E)$ is the tuition cost of attending college and the wage rate is given by

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$$\dot{a} = \begin{cases} ra - c - p_h h - p_\mu \mu(D, z) - TU_z(E) & \text{for } 0 < t \leq E, \\ ra - c - p_h h - p_\mu \mu(D, z) + w_z(D, E|\theta)\ell & \text{for } E < t \leq R, \\ ra - c - p_h h - p_\mu \mu(D, z) & \text{for } R < t \leq T. \end{cases} \quad (4)$$

where $TU_z(E)$ is the tuition cost of attending college and the wage rate is given by

$$\log w_z(t, D, E|\theta) = \log H(t, D, E|\theta) + g(E)(z + t) + \beta_0 + \beta_1(t - E) + \beta_2(t - E)^2. \quad (5)$$

Parameter $g(E)$ is the education-specific labor-augmenting technological progress

The individual (cont'd)

- **Instantaneous utility**: For simplicity' sake we define

$$\mathbf{u}(t|\phi) \equiv \begin{cases} u(c(t),0) - \phi & \text{for } 0 < t \leq E, \\ u(c(t),\ell(t)) & \text{for } E < t \leq R, \\ u(c(t),0) + \varphi(t) & \text{for } R < t \leq T, \end{cases} \tag{6}$$

$u(c,\ell) > 0$	instantaneous utility as in Murphy and Topel (2006)
ϕ	disutility of attending school: **heterogeneous access**
$\varphi(\cdot)$	utility of leisure during retirement (with $\varphi' > 0$, $\varphi'' > 0$)

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- **Lifetime utility**:

$$V(0|\phi) = \int_0^T e^{-\rho t} S(t)\mathbf{u}(t|\phi)dt \text{ with } \phi \sim \mathbb{U}(\underline{\phi},\overline{\phi}). \tag{7}$$

ρ time discount factor

Optimal life-cycle allocation

- **Value of schooling (VOS)**: Willingness to pay for H units of human capital

$$\psi^H(t) = \int_t^R e^{-r(s-t)} w_z(s, E|\theta)\ell(s)ds > 0 \text{ for } t \in (E, R). \tag{8}$$

Optimal life-cycle allocation

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- **Value of life (VOL)**: Willingness to pay for saving one's life

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$$\begin{aligned} -\psi^D(t) &= -\psi^D(T)e^{-(r-\beta_d)(T-t)} \\ &+ \int_t^T e^{-(r-\beta_d)(s-t)} \left[\mu'(D(s))(\psi^S(s) + p_\mu(s)) + \delta'(D(s))\psi^H(s)\right] ds < 0. \quad (10) \end{aligned}$$

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- **Health care investments**

$$h(t) = \left(\beta_d \eta \left(-\psi^D(t)\right) \frac{A(t)}{p_h(t)}\right)^{\frac{1}{1-\eta}}. \tag{11}$$

Optimal life-cycle allocation (cont'd)

1. **The laws of motion for consumption, labor, and health care:**

$$\dot{c}/c = \sigma_c(r - \rho - \mu(D)), \tag{12}$$

$$\dot{\ell}/\ell = \sigma_l\left(\dot{w}_z/w_z + \rho - r + \mu(D)\right), \tag{13}$$

$$\dot{h}/h = (1-\eta)^{-1}\left(r - \beta_d + \frac{\dot{A}}{A} - \frac{\dot{p}_h}{p_h} - \frac{\mu'(D)\left(\psi^S + p_\mu\right) + \delta'(D)\psi^H}{-\psi^D}\right). \tag{14}$$

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2. **Optimal retirement age**

$$\mathbf{u}_c'(R^*|\phi)w_z(D, R^*, E|\theta)\ell(R^*) = \varphi(R^*) - \alpha_l v(\ell(R^*)). \tag{15}$$

Optimal life-cycle allocation (cont'd)

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$$\mathcal{H}(T^*) = 0,\ D(t) \leq \overline{D},\ \text{and}\ D(T^*) = \overline{D}. \tag{16}$$

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$$\mathcal{H}(T^*) = 0,\ D(t) \leq \overline{D},\ \text{and}\ D(T^*) = \overline{D}. \tag{16}$$

4. **Optimal length of schooling**

$$E^* = \arg\max_{E \in \mathbb{E}} V(E, T^*, R^*, c^*, \ell^*, h^*). \tag{17}$$

The individual (cont'd)

- From Mitnitski et al. (2002) we have

$$\mu(D,z) = \gamma_\mu(z) + \alpha_\mu \left(\frac{D-\gamma_d}{\alpha_d}\right)^{\frac{\beta_\mu}{\beta_d}} \tag{18}$$

⇒ Using the health deficit model gives

$$\mu(D(t),z) = \gamma_\mu(z) + \alpha_\mu e^{\beta_\mu t + \frac{\beta_\mu}{\beta_d}\log(1-\mathrm{Re}(t,z))}, \tag{19}$$

where $\mathrm{Re}(t,z)$ is the "rejuvenation rate" at age t for the cohort z

$$0 \leq \mathrm{Re}(t,z) = \frac{\beta_d}{\alpha_d}\int_0^t A(s+z)h(s)^\eta e^{-\beta_d s} ds < 1. \tag{20}$$

health deficits

The individual (cont'd)

Let's assume a permanent medical breakthrough ξ at time τ is given by

$$A(t) = \begin{cases} \mathcal{A} & \text{for } t < \tau, \\ \mathcal{A} + \xi & \text{for } t \geq \tau. \end{cases} \tag{21}$$

Then, the relative marginal impact on the mortality hazard rate of a permanent medical breakthrough ξ at time τ is

$$-\frac{\xi}{\mu(t)} \frac{\partial \mu(t)}{\partial \xi} = \begin{cases} 0 & \text{for } t < \tau, \\ \xi \frac{\beta_\mu}{\alpha_d} \frac{\int_\tau^t h(s)^\eta e^{-\beta_d s} ds}{1 - \mathrm{Re}(t)} \left(1 - \frac{\gamma_\mu(t)}{\mu(t)}\right) & \text{for } t \geq \tau. \end{cases} \tag{22}$$

The individual (cont'd)

Figures/MedBreakthrough.jpeg

The individual (cont'd)

Figures/LongElasticity.jpeg

Optimal life-cycle allocation

- **Current-value Hamiltonian**:

$$\mathcal{H} = \begin{cases} S(u(c)-\phi) + \lambda_a(ra - c - p_h h - p_\mu \mu(D)) \\ +\lambda_h(\theta H^\gamma - \kappa D^2 H) + \lambda_D \beta_d (D - Ah^\eta - \gamma_d) & \text{schooling period,} \\ -\lambda_S \mu(D) S \\ \\ Su(c,\ell) + \lambda_a(ra + Hw\ell - c - p_h h - p_\mu \mu(D)) \\ -\lambda_h \kappa D^2 H + \lambda_D \beta_d (D - Ah^\eta - \gamma_d) & \text{working period,} \\ -\lambda_S \mu(D) S \\ \\ S(u(c)+\varphi) + \lambda_a(ra - c - p_h h - p_\mu \mu(D)) & \text{retirement period.} \\ +\lambda_D \beta_d (D - Ah^\eta - \gamma_d) - \lambda_S \mu(D) S \end{cases} \tag{23}$$

Calibration

- Three targets:

  1. Health care expenditure for 1910 birth cohort is 10% of total lifetime income, whereas for 1930 birth cohort is above 15% of total lifetime income: $\Rightarrow \bar{A}(0)$ (initial medical technology)

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  2. Evolution of life expectancy: $\Rightarrow A(t, E) = A(0, E)\exp\{\int_0^t \frac{g_h}{1+\alpha_g s} ds\}$, where g_h (medical progress)

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3. Educational distribution for 1910 birth cohort: Data taken from Edu20c.org: {Primary=48%, secondary=43%, postsecondary=8%}.

Calibration (cont'd)

- Initial endowments (ϕ, θ, D_0) are randomly drawn from uniform distributions

Calibration (cont'd)

- Initial endowments (ϕ, θ, D_0) are randomly drawn from uniform distributions
- The combination of initial endowments (ϕ, θ, D_0) influence the schooling decision $\rightarrow$ Selectivity (Less-educated individuals are more likely to come from worse socioeconomic backgrounds)

Figures/MB0.jpeg

Parameters

Table 1: Model parameters

Preferences			**Prices**		
IES on consumption	σ_c	0.6000	Productivity growth	g	0.0150
IES on labor	σ_l	0.2000	Rate of growth of health prices	g_h	0.0225
Utility weight of labor	α_l	15.0000	Interest rate	r	0.0400
Discount factor	ρ	0.0000	Initial price of health services	p_h	\$674
Initial utility of retirement	φ_0	0.5000	Initial price of emergency care	p_m	\$9 103
	φ_1	1.8559	Initial tuition cost	T_0	\$11 951
Mortality and health deficits			**Human capital**		
Natural rate of aging	β_d	0.0430	Returns to experience	β_1	0.0904
	α_d	0.0031	Returns to experience-squared	β_2	-0.0013
	γ_d	0.0200	Depreciation of human capital	κ	0.1500
Senescence rate	β_m	0.0737	Returns-to-scale to education	γ_h	0.6500
Minimum mortality rate	$\log(\alpha_m)$	-8.2630			
Makeham component	$\gamma_m(z)$	–	**Health investments**		
Maximum health deficits	$\overline{D}$	0.2200	Health technology	A	0.000547
			Returns-to-scale of health	η	0.2000

Results: Life expectancy

Figures/HealthToIncomeAv0.jpeg

Figures/HealthToIncomeAv6.jpeg

Figures/HealthToIncomeA

(a) Benchmark

(b) No medical progress + productivity growth

(c) Medical progress + no productivity growth

Figure 14: Health spending to lifetime income by cohort. Source: Authors' simulations.

Results: Life expectancy

Figures/LEe14Av0.jpeg

(a) Benchmark

Figures/LEe14Av6.jpeg

(b) No medical progress + productivity growth

Figures/LEe14Av7.jpeg

(c) Medical progress + no productivity growth

Figure 15: Cohort–life expectancy at age 14. Source: Authors' simulations and Bell et al. (1992) (red diamonds).

Results: Retirement age

Figures/RetAv0.jpeg

(a) Benchmark

Figures/RetAv6.jpeg

(b) No medical progress + productivity growth

Figures/RetAv7.jpeg

(c) Medical progress + no productivity growth

Figure 16: Retirement age by cohort, 1910–1970. Source: Authors' simulations.

Results: Lifetime income

Figures/LifeTimeIncomeAv0.jpeg

(a) Benchmark

Figures/LifeTimeIncomeAv6.jpeg

(b) No medical progress + productivity growth

Figures/LifeTimeIncome

(c) Medical progress + no productivity growth

Figure 17: Cohort–lifetime labor income. Source: Authors' simulations.

Results: Value of life (VOL)

Figures/VOLAv0.jpeg

(a) Benchmark

Figures/VOLAv6.jpeg

(b) No medical progress + productivity growth

Figures/VOLAv7.jpeg

(c) Medical progress + no productivity growth

Figure 18: Value of life (VOL) by cohort.

Source: Authors' simulations and Costa and Kahn (2004) (red diamonds).

Sensitivity analysis: Health care

Figures/HealthToIncome1.jpeg

(a) Infectious diseases

Figures/HealthToIncome3.jpeg

(b) Diff. edu. on health

Figures/HealthToIncome4

(c) Skill-biased technological change

Figure 19: Cohort health care spending share by educational attainment: Birth cohorts 1910–1970. Source: Authors' simulations.

Sensitivity analysis: Life expectancy

Figures/LEe141.jpeg

(a) Infectious diseases

Figures/LEe143.jpeg

(b) Diff. edu. on health

Figures/LEe144.jpeg

(c) Skill-biased technological change

Figure 20: Life expectancy by educational attainment: Birth cohorts 1910–1970. Source: Authors' simulations.

Sensitivity analysis: Educational attainment

Figures/EduDist1.jpeg	Figures/EduDist3.jpeg	Figures/EduDist4.jpeg
(a) Infectious diseases	(b) Diff. edu. on health	(c) Skill-biased technological change

Figure 21: Educational distribution: Birth cohorts 1910–1970. Source: Authors' simulations.

Sensitivity analysis: Retirement age

Figures/Ret1.jpeg

(a) Infectious diseases

Figures/Ret3.jpeg

(b) Diff. edu. on health

Figures/Ret4.jpeg

(c) Skill-biased technological changes

Figure 22: Retirement age by educational attainment: Birth cohorts 1910–1970. Source: Authors' simulations.

Sensitivity analysis: Lifetime income

Figures/LifeTimeIncome1.jpeg

(a) Infectious diseases

Figures/LifeTimeIncome3.jpeg

(b) Diff. edu. on health

Figures/LifeTimeIncome4

(c) Skill-biased technological change

Figure 23: Lifetime income by educational attainment: Birth cohorts 1910–1970. Source: Authors' simulations.

Sensitivity analysis: Value of life (VOL)

Figures/VOL1.jpeg

(a) Infectious diseases

Figures/VOL3.jpeg

(b) Diff. edu. on health

Figures/VOL4.jpeg

(c) Skill-biased technological change

Figure 24: Cohort value of life by educational attainment: Birth cohorts 1910–1970. Source: Authors' simulations.

Dimensions of inequality: Income

- The wage gap between males with post-college education and high school dropouts rose from 1979 through 2005

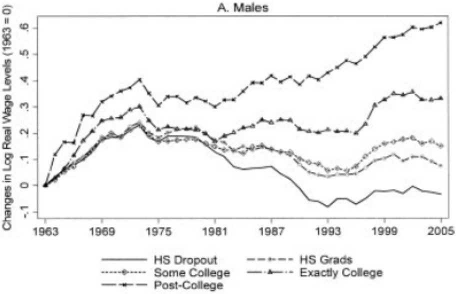
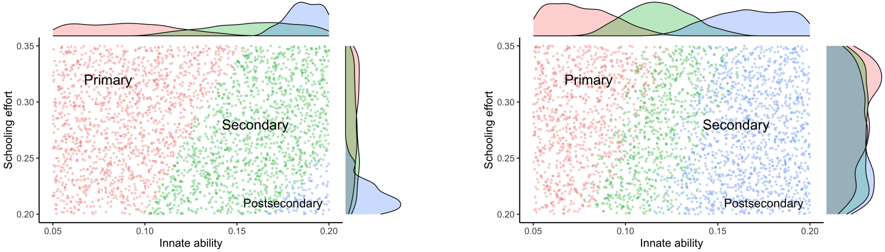


Figure 25: Trends in composition-adjusted real log weekly full-time wages by education, 1963–2005 (March CPS)
Source: Autor et al. (2008, REStat)

Calibration (cont'd)



(a) Birth cohort 1910

(b) Birth cohort 1970

Figure 26: Impact of the initial endowments on educational attainment.