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.
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)
• Inequality is multi-dimensional: education, wealth, health, etc...
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• Many of these “factors” are both drivers and outcomes of life-cycle inequality
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• **Aim**: To propose a framework for studying how (heterogeneous) individuals accumulate human capital, assets, and health deficits over the life cycle.
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  - Heterogeneity in initial endowments: learning ability, access to schooling (SES), initial health deficits
• Inequality is multi-dimensional: education, wealth, health, etc...

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• **Aim:** To propose a framework for studying how (heterogeneous) individuals accumulate human capital, assets, and health deficits over the life cycle.

  - Heterogeneity in initial endowments: learning ability, access to schooling (SES), initial health deficits

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

- **Survival and health deficit accumulation:**
  
  - Survival as a state, similar to Kuhn et al. (2015), Schünemann et al. (2017) and Dragone and Strulik (2018)
    
    \[ \dot{S} = -\mu(D, z)S \text{ with } S(0, z) = 1, \]  
    
    where \( D \) and \( z \) denote health deficits and birth cohort.
Survival and health deficit accumulation:

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  \[ \dot{S} = -\mu(D, z)S \text{ with } S(0, z) = 1, \quad (1) \]
  where \( D \) and \( z \) denote health deficits and birth cohort.

- Health deficits accumulation: Dalgaard and Strulik (2014)
  \[ \dot{D} = \beta_d (D - A(E)h^\eta - \gamma_d) \quad (2) \]
  with \( h \) health care spending, \( A(E) \) education specific medical effectiveness, \( \dot{A}(E)/A(E) = g_h/(1 + \alpha_g t) \) decreasing medical progress, \( \eta \in (0, 1) \) returns to health care investment, \( D(t) \leq \overline{D}, \quad D(T) = \overline{D}. \)

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

mortality modeling
Health- and education-dependent human capital:

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

(3)

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

**discrete educational choice:** \(E = 0\) primary; \(E = 4\) secondary; \(E = 7\) tertiary

**heterogeneous learning ability:** \(\theta \sim \mathbb{U}(\underline{\theta}, \bar{\theta})\)
Asset accumulation:

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

where \(p_h h\) is elective health care spending, \(p_{\mu \mu}(D, z)\) is emergency/acute care, \(TU_z(E)\) is the tuition cost of attending college, and where the wage rate is given by
Model III

- Asset 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. 
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where \( p_h h \) is elective health care spending, \( p_{\mu \mu}(D, z) \) is emergency/acute care, \( TU_z(E) \) is the tuition cost of attending college, and where the wage rate is given by

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

Parameter \( g(E) \) is the education-specific labor-augmenting technological progress
Instantaneous utility: For simplicity’s sake we define

\[
\begin{align*}
    u(t|\phi) = & \begin{cases} 
        u(c(t), 0) - \phi & \text{for } 0 < t \leq E, \\
        u(c(t), \ell(t)) & \text{for } E < t \leq R, \\
        u(c(t), 0) + \phi(t) & \text{for } R < t \leq T,
    \end{cases}
\end{align*}
\]

(6)

\[u(c, \ell) > 0\] instantaneous utility depending on consumption \(c\) and labour supply \(\ell\)

\[\phi\] disutility of attending school: heterogeneous access

\[\varphi(\cdot)\] utility of leisure during retirement (with \(\varphi' > 0, \varphi'' > 0\))
**Model IV**

- **Instantaneous utility**: For simplicity’s sake we define

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

\[u(c, \ell) > 0\] instantaneous utility depending on consumption \(c\) and labour supply \(\ell\)

\(\phi\) disutility of attending school: **heterogeneous access**

\(\varphi(\cdot)\) utility of leisure during retirement (with \(\varphi' > 0, \varphi'' > 0\))

- **Lifetime utility**:

\[
    V(0|\phi) = \int_0^T e^{-\rho t} S(t) u(t|\phi) dt \text{ with } \phi \sim \mathcal{U}(\phi, \bar{\phi}). \tag{7}
\]

\(\rho\) rate of time preference
Optimal life-cycle allocation

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

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

(8)
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• **Value of life (VOL):** Willingness to pay for saving one’s life

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\psi^S(t) = \int_t^T e^{-r(s-t)} \frac{u(s)}{u'_c(s)} ds > 0. \quad (9)
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• **Value of health deficits (VOD):** Willingness to pay for avoiding the accumulation of health deficits

\[
-\psi^D(t) = -\psi^D(T) e^{-(r - \beta d)(T-t)}
+ \int_t^T e^{-(r - \beta d)(s-t)} \left[ \mu'(D(s))(\psi^S(s) + p_\mu(s)) + \delta'(D(s))\psi^H(s) \right] ds > 0. \tag{10}
\]
• Value of schooling (VOS): Willingness to pay for $H$ units of human capital

$$\psi^H(t) = \int_t^R e^{-r(s-t)} w_z(s, E|\theta) \ell(s) ds > 0 \text{ for } t \in (E, R).$$  \hspace{1cm} (8)

• Value of life (VOL): Willingness to pay for saving one’s life

$$\psi^S(t) = \int_t^T e^{-r(s-t)} \frac{u(s)}{u'(s)} ds > 0.$$  \hspace{1cm} (9)

• Value of health deficits (VOD): Willingness to pay for avoiding the accumulation of health deficits

$$-\psi^D(t) = -\psi^D(T)e^{-(r-\beta_d)(T-t)}$$

$$+ \int_t^T e^{-(r-\beta_d)(s-t)} \left[ \mu'(D(s))(\psi^S(s) + p\mu(s)) + \delta'(D(s))\psi^H(s) \right] ds > 0.$$  \hspace{1cm} (10)

• Health care investments

$$h(t) = \left( \beta_d \eta \left( -\psi^D(t) \right) \frac{A(t)}{p_h(t)} \right)^{\frac{1}{1-\eta}}.$$  \hspace{1cm} (11)
1. The laws of motion for consumption, labor, and health care:

\[
\frac{\dot{c}}{c} = \sigma_c (r - \rho - \mu(D)), \quad (12)
\]

\[
\frac{\dot{\ell}}{\ell} = \sigma_l \left( \frac{\dot{w}_z}{w_z} + \rho - r + \mu(D) \right), \quad (13)
\]

\[
\frac{\dot{h}}{h} = (1 - \eta)^{-1} \left[ r - \beta_d + \frac{\dot{A}}{A} - \frac{\dot{p}_h}{p_h} - \frac{\mu'(D) (\psi^S + p_\mu) + \delta'(D) \psi^H}{\psi^D} \right]. \quad (14)
\]
Optimal life-cycle allocation II

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

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\frac{\dot{c}}{c} = \sigma_c (r - \rho - \mu(D)),
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\]

2. Optimal retirement age

\[
\mathbf{u}'_c (R^* | \phi) w_z (D, R^*, E | \theta) \ell (R^*) = \varphi (R^*) - \alpha_1 v (\ell (R^*) ) .
\]
1. The laws of motion for consumption, labor, and health care:

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\]

2. Optimal retirement age

\[
\left( u_{c}'(R^*|\phi)w_z(D, R^*, E|\theta)\ell(R^*) \right) = \phi(R^*) - \alpha_1 \nu(\ell(R^*)).
\]

3. Optimal longevity and the value of health deficits

\[
\mathcal{H}(T^*) = 0, \ D(t) \leq \overline{D}, \ \text{and} \ D(T^*) = \overline{D}.
\]
1. The laws of motion for consumption, labor, and health care:

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3. Optimal longevity and the value of health deficits

\[
H(T^*) = 0, \ D(t) \leq \overline{D}, \ \text{and} \ D(T^*) = \overline{D}.
\]

4. Optimal length of schooling

\[
E^* = \arg \max_{E \in \mathcal{E}} V(E, T^*, R^*, c^*, \ell^*, h^*).
\]
• In the numerical analysis we

1 consider random draws (> 25,000 for each scenario) from three distributions of parameters: ability ($\theta$), disutility of schooling ($\phi$) — reflecting family background—, and initial health deficits ($D(0)$).
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2. calibrate the benchmark to reflect US economy/demography for birth cohorts 1910–1970
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3. explore the role for life-cycle outcomes across and within cohorts of two secular trends: skill-biased productivity growth, $g$, and medical progress, $g_h$ (=increasing effectiveness of health care in curbing deficits)
In the numerical analysis we

1. consider random draws (> 25,000 for each scenario) from three distributions of parameters: ability (θ), disutility of schooling (φ)—reflecting family background—, and initial health deficits (D(0))

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3. explore the role for life-cycle outcomes across and within cohorts of two secular trends: skill-biased productivity growth, g, and medical progress, gh (=increasing effectiveness of health care in curbing deficits)

4. and, thus, study two counterfactuals: one without productivity growth, one without medical progress
Three targets:

1. Evolution of life expectancy: \( A(t, E) = A(0, E) \exp \left\{ \int_0^t \frac{g_h}{1 + \alpha g_s} \, ds \right\} \), where \( g_h \) (medical progress)
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2. Educational distribution for 1910 birth cohort: Data taken from Edu20c.org: {Primary=48%, secondary=43%, postsecondary=8%}. 

3. 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: \[ \bar{A}(0) \] (initial medical technology)
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Note: Medical progress has been calibrated such that medicine explains \( < 50\% \) of the increase in life expectancy
The combination of initial endowments \((\phi, \theta, D_0)\) determines the schooling decision \(\rightarrow\) Selectivity (Less-educated individuals are more likely to come from worse socioeconomic backgrounds)

Figure 3: Impact of the initial endowments on educational attainment: Cohort 1910.
Notes: Primary, Secondary, and Post-secondary
Figure 4: Labor Income: US birth cohorts 1910 (red) and 1960 (blue).
Figure 5: Assets: US birth cohorts 1910 (red) and 1960 (blue).
Results: Income gradient in life expectancy

- Strong increase over time from 2.5 years for 1910 cohort to $> 7.5$ years for 1970 cohort

**Figure 6:** Income gradient in life expectancy: Benchmark calibration.
Health care spending increases over time both within and across educational groups.

**Figure 7:** 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)

**Figure 7:** Cohort health care spending share by educational attainment. Source: Authors’ simulations and Hall and Jones (2007) (red diamonds).
Medical progress as a similarly strong driver of health care spending (Fonseca et al, 2013; Frankovic and Kuhn, 2018)

Figure 7: Cohort health care spending share by educational attainment. Source: Authors’ simulations and Hall and Jones (2007) (red diamonds).
Results: Life expectancy

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

**Figure 8:** 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

Figure 8: Life expectancy at age 14 by educational attainment. Source: Authors’ simulations and Bell et al. (1992) (red diamonds).
Productivity growth leads to an increase in the price of health care and dampens increase in life expectancy across education groups.

Figure 8: Life expectancy at age 14 by educational attainment. Source: Authors’ simulations and Bell et al. (1992) (red diamonds).
Strong educational expansion implies strong selection effects

(a) Benchmark

**Figure 9:** Educational distribution: Birth cohorts 1910–1970. Source: Authors’ simulations.
A strong Ben-Porath effect: Absence of medical progress eliminates returns of education

Figure 9: Educational distribution: Birth cohorts 1910–1970. Source: Authors’ simulations.
Results: Educational attainment

- Medical progress is key to explain the increase in education

(a) Benchmark
(b) No medical progress + productivity growth
(c) Medical progress + no productivity growth

Figure 9: Educational distribution: Birth cohorts 1910–1970. Source: Authors’ simulations.
Results: Lifetime income

- Increase in variation both across and within education groups

(a) Benchmark

**Figure 10:** Cohort lifetime labor income by educational attainment. Source: Authors’ simulations.
Results: Lifetime income

- The increase is due to productivity growth but with much less variation

(a) Benchmark  
(b) No medical progress + productivity growth

Figure 10: Cohort lifetime labor income by educational attainment. Source: Authors’ simulations.
Results: Lifetime income

- Flat incomes in the absence of productivity growth

(a) Benchmark  
(b) No medical progress + productivity growth  
(c) Medical progress + no productivity growth

**Figure 10:** Cohort lifetime labor income by educational attainment. Source: Authors’ simulations.
Results: Welfare in benchmark

- **Welfare measure:** Maximized life-cycle utility $V(c^*, l^*, S^*, E^*, R^*, T^*)$

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**Figure 11:** Normalized life-cycle utility by educational group mean and std. deviation: US birth cohorts 1910–1970.
Results: Welfare in benchmark

- **Welfare measure**: Maximized life-cycle utility \( V(c^*, l^*, S^*, E^*, R^*, T^*) \)
- **Strong increase in welfare throughout but**...

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<td></td>
<td>std.dev</td>
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<td>0.052</td>
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<td>0.083</td>
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</tr>
</tbody>
</table>

**Figure 11**: Normalized life-cycle utility by educational group mean and std. deviation: US birth cohorts 1910–1970.
Results: Welfare in benchmark

- **Welfare measure:** Maximized life-cycle utility \( V(c^*, l^*, S^*, E^*, R^*, T^*) \)
- Strong increase in welfare throughout but...
- ...increasing disparity across education groups and

<table>
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<td>1.127</td>
<td>1.151</td>
<td>1.176</td>
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**Figure 11:** Normalized life-cycle utility by educational group mean and std. deviation: US birth cohorts 1910–1970.
Results: Welfare in benchmark

- **Welfare measure:** Maximized life-cycle utility $V(c^*, l^*, S^*, E^*, R^*, T^*)$
- Strong increase in welfare throughout but...
- ...increasing disparity across education groups and
- ...within education groups, in particular the tertiary (Selection!)

<table>
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**Figure 11:** Normalized life-cycle utility by educational group mean and std. deviation: US birth cohorts 1910–1970.
Results: Welfare impact of medical progress and productivity growth

- Both medical progress and income growth contribute to increase in welfare, but...

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**Figure 12:** Normalized life-cycle utility across scenarios (cohort means and standard deviations): US birth cohorts 1910–1970.
### Results: Welfare impact of medical progress and productivity growth

- Both medical progress and income growth contribute to increase in welfare, but...
- ...medical progress provides a much stronger boost to inequality

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**Figure 12:** Normalized life-cycle utility across scenarios (cohort means and standard deviations): US birth cohorts 1910–1970.
Conclusion

• We have developed a framework for analyzing the increase in within-cohort inequality in wealth, life expectancy and wellbeing
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- Our framework accounts for compositional effects and selectivity through a set of initial endowments (learning ability, initial health deficits, and effort cost of schooling).
Conclusion

• We have developed a framework for analyzing the increase in within-cohort inequality in wealth, life expectancy and wellbeing

• Our framework accounts for compositional effects and selectivity through a set of initial endowments (learning ability, initial health deficits, and effort cost of schooling)

• Both medical progress and productivity growth turn out to be strong drivers of increases in life expectancy (here medical progress is stronger) and welfare (here productivity growth is stronger)
Conclusion

- We have developed a framework for analyzing the increase in within-cohort inequality in wealth, life expectancy and wellbeing.

- Our framework accounts for compositional effects and selectivity through a set of initial endowments (learning ability, initial health deficits, and effort cost of schooling).

- Both medical progress and productivity growth turn out to be strong drivers of increases in life expectancy (here medical progress is stronger) and welfare (here productivity growth is stronger).

- Medical progress a much stronger propensity to widen disparities mostly by triggering strong selection into education groups.
Thank you!

This project has received funding from the Austrian National Bank (OeNB) under Grant no. 17647.
The individual (cont’d)

- From Mitnitski et al. (2002) we have

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

(18)

⇒ Using the health deficit model gives

\[
\mu(D(t), z) = \gamma_\mu(z) + \alpha_\mu e^{\beta_\mu t + \frac{\beta_\mu}{\beta_d} \log(1 - Re(t, z))},
\]  

(19)

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

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

(20)
Let's assume a permanent medical breakthrough $\xi$ at time $\tau$ is given by

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

Then, the relative marginal impact on the mortality hazard rate of a permanent medical breakthrough $\xi$ at time $\tau$ is

$$-\frac{\xi}{\mu(t)} \frac{\partial \mu(t)}{\partial \xi} = \begin{cases} 0 & \text{for } t < \tau, \\ \xi \frac{\beta}{\alpha_d} \int_{\tau}^{t} h(s)^\eta e^{-\beta_d s} ds \left(1 - \frac{\gamma \mu(t)}{\mu(t)}\right) & \text{for } t \geq \tau. \end{cases} \quad (22)$$
Figure 13: Relative marginal impact on the age-specific mortality hazard rate of a permanent medical breakthrough $\xi$ at ages 20, 40, and 60.

Source: Authors' simulations.
Figure 14: Elasticity of longevity with respect to a permanent medical breakthrough. Source: Authors’ simulations.

Figures/LongElasticity.jpeg
Optimal life-cycle allocation

- **Current-value Hamiltonian:**

\[
\mathcal{H} = \begin{cases} 
S(u(c) - \phi) + \lambda_a(ra - c - p_hh - p_\mu\mu(D)) \\
+ \lambda_h(\theta H^n - \kappa D^2H) + \lambda_D\beta_d(D - Ah^n - \gamma_d) \\
- \lambda_S\mu(D)S \\
\end{cases}
\]

\[
\begin{aligned}
&\text{schooling period,} \\
&Su(c, \ell) + \lambda_a(ra + Hw\ell - c - phh - p_\mu\mu(D)) \\
&- \lambda_h\kappa D^2H + \lambda_D\beta_d(D - Ah^n - \gamma_d) \\
&- \lambda_S\mu(D)S \\
&\text{working period,} \\
&S(u(c) + \varphi) + \lambda_a(ra - c - p_hh - p_\mu\mu(D)) \\
&+ \lambda_D\beta_d(D - Ah^n - \gamma_d) - \lambda_S\mu(D)S \\
&\text{retirement period.}
\end{aligned}
\]
## Table 1: Model parameters

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<thead>
<tr>
<th>Preferences</th>
<th>Prices</th>
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<tr>
<td>IES on labor</td>
<td>( \sigma_l )</td>
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<tr>
<td>Utility weight of labor</td>
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<tr>
<td>Discount factor</td>
<td>( \rho )</td>
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<tr>
<td>Initial utility of retirement</td>
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<td>( \varphi_1 )</td>
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<th>Human capital</th>
<th>Health investments</th>
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<td>( \gamma_d )</td>
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<td>( D )</td>
<td>Health technology</td>
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<tr>
<td></td>
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<td>Returns-to-scale of health</td>
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</tbody>
</table>
Results: Life expectancy

(a) Benchmark
(b) No medical progress + productivity growth
(c) Medical progress + no productivity growth

Figure 15: Health spending to lifetime income by cohort. Source: Authors’ simulations.
Figure 16: Cohort–life expectancy at age 14. Source: Authors’ simulations and Bell et al. (1992) (red diamonds).
Figure 17: Retirement age by cohort, 1910–1970. Source: Authors’ simulations.
**Results: Lifetime income**

*Figure 18:* Cohort–lifetime labor income. Source: Authors’ simulations.
Results: Value of life (VOL)

Figure 19: Value of life (VOL) by cohort.

Figure 20: Cohort health care spending share by educational attainment: Birth cohorts 1910–1970. Source: Authors’ simulations.
Sensitivity analysis: Life expectancy

Figure 21: Life expectancy by educational attainment: Birth cohorts 1910–1970. Source: Authors' simulations.
Sensitivity analysis: Educational attainment

Figure 22: Educational distribution: Birth cohorts 1910–1970. Source: Authors’ simulations.
Sensitivity analysis: Retirement age

(a) Infectious diseases
(b) Diff. edu. on health
(c) Skill-biased technological changes

Figure 23: Retirement age by educational attainment: Birth cohorts 1910–1970. Source: Authors’ simulations.
Sensitivity analysis: Lifetime income

Figure 24: Lifetime income by educational attainment: Birth cohorts 1910–1970. Source: Authors' simulations.
Sensitivity analysis: Value of life (VOL)

(a) Infectious diseases

(b) Diff. edu. on health

(c) Skill-biased technological change

Figure 25: Cohort value of life by educational attainment: Birth cohorts 1910–1970. Source: Authors’ simulations.
The wage gap between males with post-college education and high school dropouts rose from 1979 through 2005.

**Figure 26:** Trends in composition-adjusted real log weekly full-time wages by education, 1963–2005 (March CPS)  
Source: Autor et al. (2008, REStat)
(a) Birth cohort 1910
(b) Birth cohort 1970

**Figure 27**: Impact of the initial endowments on educational attainment.