The Shape of Mortality: Implications for Economic Analysis

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September 2016
Question: What is the production function of health over lifetime?

1. What is the effect of economic conditions on mortality?
   • Puzzle in literature: Effect of GDP level and of deviations from trend.
   • Money in short and run long has different effects on health

2. Why is LE of women larger and growing faster than men’s?
   • Biological differences versus social investments & innovation (how many missing women?)

3. What is the optimal sequence of health investments over the lifetime?
   • Health care expenditures by age?
   • SES gradients: Can initial conditions be overcome?

To answer these questions we need estimates of the “production” function of health over the lifetime.

Key insight here: Mortality rates by age reveal health process
This paper: A simple tractable model of cohort health and death

**Model:** health = dynamic stock of “Frailty”. Four “fundamental” forces affect stock and generate deaths

1. Resources/investments increase stock
2. Disease: random shocks. Can hit anyone but more likely kill the frail
3. Depreciation: natural aging process.
4. “External causes of death,” mostly reproductive ages (M, war, etc)

**Estimation of parameters**

- Use newly available cohort life tables from Human mortality database
- Use simulation method of moments
- Study evolution of parameters over time their correlates

**Investigate implications**

- For economic decisions incorporating health and mortality
- Interpret findings in empirical literature
Data: Human Mortality Database (HMD)

- Highest quality **cohort** life tables reporting mortality rates by year of birth, gender and age
- Use cohorts born 1860-1930 from 11 countries observed until 2010
  - Observe mortality from birth to age 90 (MR imputed after)

<table>
<thead>
<tr>
<th>Country</th>
<th>Earliest fully observed birth cohort we use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>1860</td>
</tr>
<tr>
<td>France</td>
<td>1860</td>
</tr>
<tr>
<td>Denmark</td>
<td>1860</td>
</tr>
<tr>
<td>Iceland</td>
<td>1860</td>
</tr>
<tr>
<td>Belgium</td>
<td>1860</td>
</tr>
<tr>
<td>Norway</td>
<td>1860</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1860</td>
</tr>
<tr>
<td>Italy</td>
<td>1872</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1876</td>
</tr>
<tr>
<td>Finland</td>
<td>1878</td>
</tr>
<tr>
<td>Spain</td>
<td>1908</td>
</tr>
<tr>
<td>Australia</td>
<td>1921</td>
</tr>
<tr>
<td>Canada</td>
<td>1921</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1922</td>
</tr>
</tbody>
</table>
Log mortality is (almost) shaped like a check mark.

- Falls fast in childhood
- Low, flat and variable during reproductive ages
- Is linear on old age (Gompertz (1825)). After age 45: Lines move in parallel (as mortality falls)
- Lines don’t cross
“External factors” matter most in reproductive ages.

Weighted to a world population using samples present in that year.
Search for a unified model of mortality: focus on modeling hazard rates

- Gompertz (1825): log-linearity after age 40
- Non-monotonic hazard: avoid by using Cox proportional hazard
- Best parametric fit to date: Heligman and Pollard (1980)

Parametric approach here: model & estimate evolution of health consistent with shape of mortality

- Related to recent models of vitality models Li and Anderson (2013)
- Grossman (1972) or Case & Deaton (2005): here add shocks
- Heckman and Cuhna (2007): stochastic, applied to health/mortality
- Make the stock a function of initial frailty as Vaupel et al (1979) but dynamic
- Shocks shift distribution (Bozzoli et al, 2009; Bruckner et al. 2007) but every period.

Model biological processes & add shock to account for “Bump”

- Intuition from Carnes et al: eliminate “external” causes during reproductive ages
A model of “natural” mortality
What would female mortality look like without maternal mortality?

Log of mortality for Women born in Sweden 1820-1940

For 1910 cohort

J-shape

Consistent with declines in MM

Data: Human Mortality Database
Similar for males as violence and accidents decline

Log of mortality for Men born in Sweden 1820-1940

For more recent cohorts: J-shape

Data: Human Mortality Database
A dynamic model of health

\[ H_0 \sim N(\mu_H, \sigma_H^2) \]

\[ H_t = H_{t-1} + I(Y_t, B_t) - \delta t^\alpha + \varepsilon_t \quad \varepsilon_t \sim i.i.d. N(0, \sigma_\varepsilon^2) \]

Die when \( H_t < H \)

- **Initial conditions** \( \mu_H \): distance from death threshold at birth
- **Environment determines**
  - **Resources** I: Average annual investment. Can be zero. Can be affected by inputs like food \( (Y) \) and pollution \( (B) \)
  - **Disease** \( \sigma_\varepsilon^2 \): random shock hits individuals independently of their health, but is more likely to kill those with large unlucky shocks or who start with poor levels of health. Cannot be zero.
  - **Aging** \( (\alpha, \delta) \): cannot be zero, cannot be constant over time.
How is mortality determined?

\[ MR_1 = P(H_1 \leq H) = P(H_0 + I(Y_1, B_1) - \delta + \varepsilon_1 \leq H) \]

Infant mortality: Area under curve, depends a lot on initial distribution

*Scale and location are not identified: normalize \( H = 0, \sigma_H^2 = 1 \)
How is mortality determined? (cont’ed)

*without shocks: no mortality after age 1!

*Mortality at age 2: Area under curve, depends a lot on shock

*mortality at age t depends on entire history of shocks
Evolution of health stock over the ages

Distribution moves right and widens then moves left but tail continues to expand

90-years old are on average as frail as babies. But some are as healthy as 40-yr olds
Simulated evolution of mortality and average stock

- **Min mortality**: age 20
- **Max health stock**: age 40
- **Max sd of health**: age 60
Changing initial conditions: effect in logs

Huge effect on IMR

Permanent effects
Consistent with findings on in-utero shocks

Lines converge in old age
Never cross

H at birth=68
H at birth = 78
Gaps in mortality rates between $H_0$-rich and $H_0$-poor:

-0.04
-0.03
-0.02
-0.01
0

“gradient” huge, declines and re-appears after age 60
Grows with age
Never as big as gap at 1

Rich mean 76 (BEL 1930)
Poor mean 68 (BEL 1860)
Changing Annual Investment: effect in logs

- Small effect at birth
- Gaps are almost Constant but Converging
- Never cross
Gaps in mortality rates between I-rich and I-poor

Gaps emerge and increase with age. Much larger gaps in old age than at one.

H gaps show up more at birth, I gaps later in life.

I-poor: 4.5 (BEL 1860)
I-rich: 4.8 (BEL 1910)
Health gaps among living between I-rich and I-poor

Mean health gap

Grow monotonically with age

But fall at older ages when mortality rates become large

Consistent with Case et al (2002): SRHS gaps by family income follow this pattern
Investments over the lifetime are complementary

Consistent with Heckman and Cuhna (2013)
Changing standard deviation of disease shock: “what doesn’t kill you makes you stronger” effect

Curves cross!

With large variance
A few very “lucky”
With large positive shocks

SD 16 (blue) v. SD of 10 (red)
Mortality gap reverses

- The gap reverses as age increases.
- Similar to the crossover for blacks relative to whites in the US.
- The gradient falls with age and reverses.

Small variance 10 (BEL 1920)
Large variance 16 (BEL 1860)

Similar to cross over for blacks relative to whites in US.
Higher variance = positive gaps that turn negative.

The survivors in the high variance population have higher health in old age (on average): they received large positive shocks.
Could we use only 1 parameter to describe aging? No, they govern the starting point (intercept) and slope of aging.

These “dominate” mortality in old age but the slope in old age is a function of ALL the parameters in the model.
Gaps in mortality when aging parameters vary

Increase in either parameter results in gaps that
* are almost zero before age 45
* grow with age thereafter
Gaps in health when aging varies

Increase in either parameter results in gaps that grow and then fall with age.

Initial $H_0$, $I$ and Aging parameter changes all have similar effects. They can only be separated by effects at younger ages.

* $H$ shows up a lot at birth
* $I$ shows throughout
* Aging only after 45
Final comment: Selection forces are weak

- Selection effects never dominate, curves do not cross.

- For changes in SD they do, but not because of selection (trimming of weakest). Rather because some lucky individuals receive a sequence of large positive shocks.
Estimating parameters

- Use simulated method of moments
  - Find parameters that make simulated mortality closest to actual mortality
    - Specifically: Minimize sum of absolute errors in ln(MR)
  - Uses mortality rates at every age EXCEPT for Ages 15-45

- Recover parameters for each cohort
- Estimate for all cohorts

(SE: under construction)
Belgian women: 1860-1930
Belgian men: 1860-1930
Predicted LE is larger than observed

- underestimating MR at old ages:
  - Could target LE (or level of MR) as the objective to match? Currently minimizing sum of errors in log(mortality rates)
  - Could also chose “endogenously” what the cutoff points

- Downward bias by design: we ignore shocks ages 15-45 (mostly negative ones). More later.
The sources of progress: Belgian males 1860-1910

<table>
<thead>
<tr>
<th>Birth cohort</th>
<th>1860</th>
<th>1870</th>
<th>1880</th>
<th>1890</th>
<th>1900</th>
<th>1910</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean health at birth</td>
<td>0.941</td>
<td>0.963</td>
<td>1.011</td>
<td>0.963</td>
<td>1.061</td>
<td>0.973</td>
</tr>
<tr>
<td>Variance of shocks</td>
<td>0.460</td>
<td>0.378</td>
<td>0.368</td>
<td>0.386</td>
<td>0.391</td>
<td>0.355</td>
</tr>
<tr>
<td>Average investment</td>
<td>0.129</td>
<td>0.138</td>
<td>0.130</td>
<td>0.138</td>
<td>0.140</td>
<td>0.135</td>
</tr>
<tr>
<td>Depreciation rate</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0011</td>
<td>0.0013</td>
<td>0.0012</td>
<td>0.0012</td>
</tr>
<tr>
<td>Aging rate</td>
<td>1.348</td>
<td>1.356</td>
<td>1.356</td>
<td>1.342</td>
<td>1.358</td>
<td>1.334</td>
</tr>
</tbody>
</table>

Largest changes in variance of shocks (-23%), investment (5%) and mean at birth (3%)

No changes in depreciation or aging rate
# The sources of progress: Belgian females 1860-1910

<table>
<thead>
<tr>
<th>Birth cohort</th>
<th>1860</th>
<th>1870</th>
<th>1880</th>
<th>1890</th>
<th>1900</th>
<th>1910</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean health at birth</td>
<td>0.939</td>
<td>0.983</td>
<td>0.973</td>
<td>0.973</td>
<td>1.025</td>
<td>1.160</td>
</tr>
<tr>
<td>Variance of shocks</td>
<td>0.464</td>
<td>0.393</td>
<td>0.355</td>
<td>0.364</td>
<td>0.327</td>
<td>0.367</td>
</tr>
<tr>
<td>Average investment</td>
<td>0.135</td>
<td>0.134</td>
<td>0.131</td>
<td>0.129</td>
<td>0.130</td>
<td>0.143</td>
</tr>
<tr>
<td>Depreciation rate</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0011</td>
<td>0.0011</td>
<td>0.0011</td>
</tr>
<tr>
<td>Aging rate</td>
<td>1.342</td>
<td>1.334</td>
<td>1.335</td>
<td>1.333</td>
<td>1.320</td>
<td>1.340</td>
</tr>
</tbody>
</table>

Largest changes in mean at birth (24%). variance of shocks (-21%), investment (6%). Depreciation decline 11%
No change in aging rate.
In all cases health at birth & investment has increased substantially up to 1910
- Standard deviation of shock declines range from 17-32%: huge!
- Slope of again: almost identical across countries & periods.
- WW2: BIG shock
## Females in Belgium, Norway and France

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Country</th>
<th>Annual investment</th>
<th>Delta</th>
<th>sd of shocks</th>
<th>Gamma</th>
<th>H₀ mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1860</td>
<td>Belgium</td>
<td>0.135</td>
<td>1.219E-03</td>
<td>0.464</td>
<td>1.3420</td>
<td>0.939</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>0.130</td>
<td>1.201E-03</td>
<td>0.418</td>
<td>1.3512</td>
<td>1.112</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>0.132</td>
<td>1.189E-03</td>
<td>0.470</td>
<td>1.3294</td>
<td>1.001</td>
</tr>
<tr>
<td>1910</td>
<td>Belgium</td>
<td>0.143</td>
<td>1.071E-03</td>
<td>0.367</td>
<td>1.3155</td>
<td>1.160</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>0.147</td>
<td>1.291E-03</td>
<td>0.345</td>
<td>1.3039</td>
<td>1.043</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>0.164</td>
<td>7.241E-04</td>
<td>0.378</td>
<td>1.4528</td>
<td>1.459</td>
</tr>
<tr>
<td>1920</td>
<td>Belgium</td>
<td>0.132</td>
<td>9.769E-04</td>
<td>0.329</td>
<td>1.3440</td>
<td>1.176</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>0.134</td>
<td>1.094E-03</td>
<td>0.359</td>
<td>1.3155</td>
<td>1.194</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>0.166</td>
<td>1.292E-03</td>
<td>0.348</td>
<td>1.3073</td>
<td>1.340</td>
</tr>
</tbody>
</table>

- Patterns for women identical
Female advantage: initial $H$ has increased a lot more for women (I a bit too)

Either more inputs or women are more responsive to inputs
Across countries: 1870-1920 as % of 1870

<table>
<thead>
<tr>
<th>Gender</th>
<th>Country</th>
<th>Annual investment</th>
<th>Delta</th>
<th>sd of shocks</th>
<th>Gamma</th>
<th>H₀ mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Belgium</td>
<td>2.22%</td>
<td>19.86%</td>
<td>29.09%</td>
<td>-0.15%</td>
<td>-25.24%</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>-3.08%</td>
<td>8.91%</td>
<td>14.11%</td>
<td>2.64%</td>
<td>-7.37%</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>-25.76%</td>
<td>-8.66%</td>
<td>25.96%</td>
<td>1.66%</td>
<td>-33.87%</td>
</tr>
<tr>
<td>Female</td>
<td>Belgium</td>
<td>-1.55%</td>
<td>-15.28%</td>
<td>31.85%</td>
<td>2.39%</td>
<td>-19.81%</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>4.65%</td>
<td>10.45%</td>
<td>20.97%</td>
<td>2.44%</td>
<td>-8.13%</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>-23.08%</td>
<td>5.47%</td>
<td>16.67%</td>
<td>-2.24%</td>
<td>-23.93%</td>
</tr>
</tbody>
</table>

- In all cases health at birth increased more for women.
- In all cases standard deviation of shock fell more for women.
- Investment results depend a lot on country.
- Changes in aging slope close to zero.
Some observations

- Large decreases in variance of shocks:
  - Public health improvements: decline of infectious disease level and cyclicality of morbidity (e.g., flu)
  - Larger “social insurance” rates: savings, public spending, decrease in famine mortality
    - Improvements in data collection (smaller measurement error in MR)?

- $H_0$ going up: like birth weight and other measures of health at birth
  - Intergenerational component might be important too
  - In-utero shocks and nutrition matter (Barker 1975)

- Increases in $H$ and $I$ consistent with large secular increases in GDP (in BEL and many other countries during this period)—and associated increases in food and public health investments.
Understanding parameter sizes: SES gradients

Chetty et al (2016)

How big is the gap?

“the gap in life expectancy between individuals in the top and bottom 1% of the income distribution in the United States is 15 years for men and 10 years for women”

Suggest main differences by income at age 40 driven by pre-age 40 Conditions: either $H_0$ or $I$

Differences here much larger than changes in initial conditions or $I$ in Belgium from 1860-1930. (combined?)
How to account for mortality during reproductive ages?
What are the main causes of death 15-45?

- **Men**: Injury (War, violent deaths and accidents).
  - (Mostly) Unrelated to health, income?
  - In peace times greatly influenced by by alcohol consumption & vehicle use (normal goods), gun availability, violence (related to SES)
  - War might or might not kill on the basis of H

- **Women**: Maternal Mortality
  - Sepsis (puerperal fever) main cause ~40%, hemorrhage second.
  - SES & nutrition play small role relative to hygiene and “intervention” not H
    - Complications at birth very difficult to predict

**Generic model likely will fail:**
- Timing and deadliness of war by age vary over time and place
- MM a function of fertility rates and conditions at birth
Adding External Causes to the model

Three possibilities that involve ONE more parameter

1. **I-shock**: Lower I during reproductive ages
   - \[ H_t = H_{t-1} + I(Y_t, B_t) - \kappa \times D(= 1 \text{ if } 15 < t < 45) - \delta t^\alpha + \varepsilon_t \]

2. **Accident**: Random death shock, healthy and sick equally likely to die
   - Die when \( H_t < \underline{H} \) OR when new i.i.d. term \( U[0-1] < \kappa \) if \( 15 < t < 45 \)

3. Change in death **threshold**: \( \underline{H} = \underline{H} + \kappa \) if \( 15 < t < 45 \)

4. Increases in **variance**:
   - \( \varepsilon_t \sim N(0, \sigma^2_\varepsilon) \) if \( 15 > t \) or \( t > 45 \)
   - \( \varepsilon_t \sim N(0, \sigma^2_\varepsilon + \kappa) \) if \( 15 < t < 45 \)

   * Assumes ages (15-45) are fixed and known, otherwise 3 new parameters
Higher “Accident” risk throughout life: higher MR

Curve shifts up.

Cannot by itself explain bump.

Looks like I or H change!!

Curves converge

age

baseline  A 0.005 accident rate
BUT mortality gaps are constant by construction
Simulated shock between ages 15 and 25

- Variance: permanent lower rate
- Threshold: huge selection in ST
- Only I-shocks cumulate and de-cumulate
- Looks + like a war

Baseline
Accident increase
Variance increase
Threshold increase
Suggests additional empirical tests

- Regression-based test, for mortality after ages 45 regress:

\[
\ln MR_t = c_0 + b_0 * \text{age} + c_1 * \ln MR_{1-14} + b_1 * \text{age} * \ln MR_{1-14} + c_2 * \ln MR_{15-45} + b_2 * \ln MR_{15-45} * \text{age} + \epsilon_t
\]

- If initial conditions matter, \(c_1\) and \(b_1\) will be non-zero

- If shocks during reproductive ages are
  - "accidents" then \(c_2\) and \(b_2\) will be equal to zero
  - variance changes then \(c_2 < 0\) and \(b_2 = 0\)
  - I-shocks then \(c_2 > 0\) and \(b_2 < 0\)
  - Threshold shocks: \(c_2 < 0\) and \(b_2 > 0\)

- Alternative test: if observe H can do AR estimation?
**Women in HMDB: Bump is not random**

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>Basic Women</th>
<th>Add reproductive mortality</th>
<th>Add child mortality</th>
<th>Separate under age 2-14 mortality</th>
<th>Individual 2-14 mortality</th>
<th>Country FE</th>
<th>Birth year FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-4.889***</td>
<td>-3.852***</td>
<td>-3.853***</td>
<td>-5.341***</td>
<td>-5.271***</td>
<td>-5.329***</td>
<td>-5.335***</td>
</tr>
<tr>
<td></td>
<td>[0.0137]</td>
<td>[0.0186]</td>
<td>[0.0272]</td>
<td>[0.0720]</td>
<td>[0.0660]</td>
<td>[0.0728]</td>
<td>[0.0616]</td>
</tr>
<tr>
<td>Age</td>
<td>0.0865***</td>
<td>0.0789***</td>
<td>0.0764***</td>
<td>0.0909***</td>
<td>0.0893***</td>
<td>0.0894***</td>
<td>0.0892***</td>
</tr>
<tr>
<td></td>
<td>[0.000198]</td>
<td>[0.000270]</td>
<td>[0.000395]</td>
<td>[0.00105]</td>
<td>[0.000960]</td>
<td>[0.000913]</td>
<td>[0.000895]</td>
</tr>
<tr>
<td>Ln(MR 15-45)</td>
<td>1.213***</td>
<td>1.212***</td>
<td>1.137***</td>
<td>1.176***</td>
<td>1.092***</td>
<td>1.165***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[0.0198]</td>
<td>[0.0514]</td>
<td>[0.0514]</td>
<td>[0.0561]</td>
<td>[0.0547]</td>
<td>[0.0540]</td>
<td></td>
</tr>
<tr>
<td>Ln(MR 15-45)*Age</td>
<td>-0.00881***</td>
<td>-0.0146***</td>
<td>-0.0146***</td>
<td>-0.0152***</td>
<td>-0.0150***</td>
<td>-0.0149***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[0.000288]</td>
<td>[0.000747]</td>
<td>[0.000746]</td>
<td>[0.000813]</td>
<td>[0.000773]</td>
<td>[0.000758]</td>
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</tr>
<tr>
<td>Observations</td>
<td>16,461</td>
<td>16,461</td>
<td>16,461</td>
<td>16,061</td>
<td>13,497</td>
<td>13,497</td>
<td>13,497</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.920</td>
<td>0.970</td>
<td>0.973</td>
<td>0.976</td>
<td>0.982</td>
<td>0.984</td>
<td>0.984</td>
</tr>
</tbody>
</table>

Higher intercept and flatter slope: looks like I-shock
Men in HMDB: Bump is not random

<table>
<thead>
<tr>
<th>VARIABLES</th>
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<th>Add reproductive mortality</th>
<th>Add child mortality</th>
<th>Separate under age 2-14 mortality</th>
<th>Individual 2-14 mortality</th>
<th>Country FE</th>
<th>Birth year FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-4.889***</td>
<td>-3.638***</td>
<td>-3.559***</td>
<td>-5.628***</td>
<td>-5.449***</td>
<td>-4.888***</td>
<td>-5.595***</td>
</tr>
<tr>
<td></td>
<td>[0.0137]</td>
<td>[0.0143]</td>
<td>[0.0149]</td>
<td>[0.0601]</td>
<td>[0.0619]</td>
<td>[0.0608]</td>
<td>[0.0585]</td>
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<tr>
<td>Age</td>
<td>0.0865***</td>
<td>0.0764***</td>
<td>0.0751***</td>
<td>0.0957***</td>
<td>0.0930***</td>
<td>0.0932***</td>
<td>0.0930***</td>
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<tr>
<td></td>
<td>[0.000198]</td>
<td>[0.000207]</td>
<td>[0.000215]</td>
<td>[0.000873]</td>
<td>[0.000899]</td>
<td>[0.000776]</td>
<td>[0.000846]</td>
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<tr>
<td>Ln(MR 15-45)</td>
<td>1.083***</td>
<td>1.484***</td>
<td>1.566***</td>
<td>1.466***</td>
<td>1.224***</td>
<td>1.560***</td>
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<tr>
<td></td>
<td>[0.0174]</td>
<td>[0.0294]</td>
<td>[0.0270]</td>
<td>[0.0328]</td>
<td>[0.0307]</td>
<td>[0.0311]</td>
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</tr>
<tr>
<td>Ln(MR 15-45)*Age</td>
<td>-0.0116***</td>
<td>-0.0182***</td>
<td>-0.0191***</td>
<td>-0.0174***</td>
<td>-0.0174***</td>
<td>-0.0173***</td>
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<tr>
<td></td>
<td>[0.000253]</td>
<td>[0.000425]</td>
<td>[0.000391]</td>
<td>[0.000472]</td>
<td>[0.000408]</td>
<td>[0.000444]</td>
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<tr>
<td>Observations</td>
<td>16,461</td>
<td>16,461</td>
<td>16,461</td>
<td>16,061</td>
<td>13,497</td>
<td>13,497</td>
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<tr>
<td>R-squared</td>
<td>0.92</td>
<td>0.976</td>
<td>0.977</td>
<td>0.982</td>
<td>0.984</td>
<td>0.988</td>
<td>0.986</td>
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</tbody>
</table>

Higher intercept and flatter slope: looks like I-shock
How to best characterize reproductive ages

Estimation in three steps:

1. Estimate model “outside reproductive ages”

2. Estimate bump 4 times (for each possible model of the bump)
   • Using the parameters from step 1 as given and fixed

3. Re-estimate full model allowing all parameters to move
   • so far only adding one parameter
   • Eventually also allow for beginning and end point to be estimated.
Evidence from SMM estimates

IN CONSTRUCTION
What’s next?
Does GDP predict changes in parameters?

PLAN

- Re-estimate for all cohorts between 1850-1930: 80 estimates for each parameter

- Regress each parameter on GDP at birth, or GDP at age 20, or GDP at age 40, or GDP at age 60

- which GDP is the largest predictor for each measure?
  - Report raw correlation, beta from regression and R-squared.
Implications for optimal investments

- Compute ST and LT rate of return at each age

- Solve investment allocation problem
  - Maximize years lived in the population under fixed budget
  - Consumption and health investment, with health affecting wages and probability of dying
What’s next?

Worth doing for all country*cohorts?
*need improvements in fit
*compute standard errors
*constraint parameters across cohorts?
*investigate how good predictions are with data on first 15 years for a cohort?

Obtain estimates of $H$ for a cohort?
Close form solutions or approximations?
Implications for intergenerational transmission of health?
Heligman and Pollard’s function 1980

- Model log odds of dying at age a (ratio of the probability of dying at age x to that of the probability of not dying at age x), i.e.

\[ \frac{Q_x}{p_x} = \frac{(1 - p_x)}{p_x} = A^{(x+B)C} + D \cdot \exp \left( -E \cdot (\ln(x) - \ln(F))^2 \right) + GH^x \]

- A, B and C: capture the rapid decline in child mortality at younger ages.
- G and H: Gompertz mortality function in old age
- D, E and F: reflects the ‘accident hump’ or the effects of maternal mortality among women.
Consistent with trends in maternal mortality

Figure 2, Loudon (2000)
Follows findings in Case, Paxson and Lubotsky

**Figure 1. Health and Income for Children and Adults: NHIS (1986–1995) and PSID**