Appendix for

Male excess mortality during the epidemiological transition: theory and evidence from India

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Appendix A. Items in the Frailty Index

The frailty index is based on prevalence rates for the following diseases (32 in total):

Diarrheal diseases; Protein-energy malnutrition; Neoplasms; Ischemic heart disease; Stroke; Non-rheumatic valvular heart disease; Cardiomyopathy and myocarditis; Atrial fibrillation and flutter; Peripheral artery disease; Other cardiovascular and circulatory diseases; Chronic respiratory diseases; Peptic ulcer disease; Gallbladder and biliary diseases; Alzheimer's disease and other dementias; Parkinson's disease; Depressive disorders; Diabetes mellitus; Chronic kidney disease; Skin and subcutaneous diseases; Other sense organ diseases; Rheumatoid arthritis; Osteoarthritis; Low back pain; Gout; Urinary diseases and male infertility; Genital prolapse; Endocrine, metabolic, blood, and immune disorders; Oral disorders; Falls; Hearing loss; Heart failure; Blindness and vision loss.

Appendix B. Proof of Proposition 1

The proof begins with inserting (5) in the definition of excess mortality, which provides:

$$\tilde{m}^C(t,v) = \frac{\eta_M D_M(t,v)^{\gamma_M}}{\eta_F D_F(t,v)^{\gamma_F}}. \tag{B.1}$$

Taking logs and then the derivative with respect to $e_0(v)$ provides the condition

$$\frac{\mathrm{d}\log \tilde{m}^C(t,v)}{\mathrm{d}e_0(v)} = \frac{\gamma_M}{D_M(t,v)}\frac{\partial D_M(t,v)}{\partial e_0(v)} - \frac{\gamma_F}{D_F(t,v)}\frac{\partial D_F(t,v)}{\partial e_0(v)} < 0 \tag{B.2}$$

for $\mathrm{d}\tilde{m}^C(t,v)/\mathrm{d}e_0(v) < 0$ since $\log(x)$ is an increasing function of x. Rearranging (B.2) provides condition (7).

From (4) we obtain for males:

$$\frac{\partial D_M(t,v)}{\partial e_0(v)} = \frac{\alpha_M \mathrm{e}^{\mu t}}{\mu_m + \beta}\left[1 - e^{-(\mu_M+\beta)t}\right]$$

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and thus

$$\frac{D_M(t,v)}{\partial D_M(t,v)/\partial e_0(v)} = D_{M0}\frac{\mu_M+\beta}{\alpha_M}\frac{1}{1-\mathrm{e}^{-(\mu_M+\beta)t}} + e_0(v)$$

and likewise for females. Using this information, condition (B.2) can be restated as:

$$\frac{\gamma_M}{e_0(v)+\frac{\mu_M+\beta}{\alpha_M}\frac{D_{M0}}{1-\mathrm{e}^{-(\mu_M+\beta)t}}} - \frac{\gamma_F}{e_0(v)+\frac{\mu_F+\beta}{\alpha_F}\frac{D_{F0}}{1-\mathrm{e}^{-(\mu_F+\beta)t}}} < 0$$

that is

$$\frac{\gamma_M}{\gamma_F} < \frac{e_0(v)+\frac{\mu_M+\beta}{\alpha_M}\frac{D_{M0}}{1-\mathrm{e}^{-(\mu_M+\beta)t}}}{e_0(v)+\frac{\mu_F+\beta}{\alpha_F}\frac{D_{F0}}{1-\mathrm{e}^{-(\mu_F+\beta)t}}}$$

Under the made assumptions the left-hand side is equal or smaller than one. A sufficient condition for (B.2) to hold is therefore

$$\frac{\mu_M+\beta}{\alpha_M}\frac{D_{M0}}{1-\mathrm{e}^{-(\mu_M+\beta)t}} > \frac{\mu_F+\beta}{\alpha_F}\frac{D_{F0}}{1-\mathrm{e}^{-(\mu_F+\beta)t}},$$

that is

$$LHS \equiv \frac{1-\mathrm{e}^{-(\mu_F+\beta)t}}{1-\mathrm{e}^{-(\mu_M+\beta)t}} > \frac{D_{F0}}{D_{M0}}\frac{(\mu_F+\beta)}{(\mu_M+\beta)}\frac{\alpha_M}{\alpha_F}. \tag{B.3}$$

To continue with the proof we first state the following lemma.

LEMMA 1. *The LHS in equation (B.3) is strictly increasing in t with a minimum at $t=0$ that equals $(\mu_F+\beta)/(\mu_M+\beta)$.*

For the proof of the Lemma, we discuss the derivative

$$\frac{\partial LHS}{\partial t} = \frac{(\mu_F+\beta)\mathrm{e}^{-(\mu_F+\beta)t}\left[1-\mathrm{e}^{-(\mu_M+\beta)t}\right] - (\mu_M+\beta)\mathrm{e}^{-(\mu_M+\beta)t}\left[1-\mathrm{e}^{-(\mu_F+\beta)t}\right]}{\left[1-\mathrm{e}^{-(\mu_M+\beta)t}\right]^2}.$$

The derivative is positive if the numerator is positive, that is if

$$\left(1-\mathrm{e}^{-at}\right)\left(1-\mathrm{e}^{-bt}\right)\left[\frac{ae^{-at}}{1-e^{-at}} - \frac{be^{-bt}}{1-e^{-bt}}\right] > 0$$

with $a=\mu_F+\beta$ and $b=\mu_M+\beta$. Since the first two terms are positive, the derivative is positive if

$$\frac{ae^{-at}}{1-e^{-at}} > \frac{be^{-bt}}{1-e^{-bt}}. \tag{B.4}$$

To show that condition (B.4) holds, define

$$f(z) \equiv \frac{ze^{-zt}}{1-e^{-zt}}.$$

The derivative is with respect to z is:

$$f'(z) = -\frac{1+(zt-1)e^{zt}}{[1-e^{-zt}]^2} < 0, \quad \forall t > 0.$$

A since we have $\mu_M > \mu_F$ and thus $b > a$, we have $f(a) > f(b)$. Thus condition (B.4) is fulfilled. Therefore, $\partial LHS/\partial t > 0$. This proves the Lemma. □

Lemma 1 shows that LHS increases monotonously in age t. The upper bound is where $\lim_{t\to\infty} LHS = 1$ and using L'Hôpital's rule we obtain the lower bound:

$$\lim_{t\to 0} LHS = \lim_{t\to 0} \frac{(\mu_F+\beta)\mathrm{e}^{-(\mu_F+\beta)t}}{(\mu_M+\beta)\mathrm{e}^{-(\mu_M+\beta)t}} = \frac{\mu_F+\beta}{\mu_m+\beta}.$$

As sufficient condition for (B.2) to be fulfilled is thus

$$\frac{\mu_F+\beta}{\mu_m+\beta} > \frac{D_{F0}}{D_{M0}} \frac{(\mu_F+\beta)}{(\mu_M+\beta)} \frac{\alpha_M}{\alpha_F} \quad \Leftrightarrow \quad \frac{\alpha_F}{\alpha_M} > \frac{D_{F0}}{D_{M0}},$$

which provides condition (8) and completes the proof. □

Appendix C. Additional Figures

Figure A.1. Male Excess NCD Mortality by Cohort

A. Age 45 B. Age 65

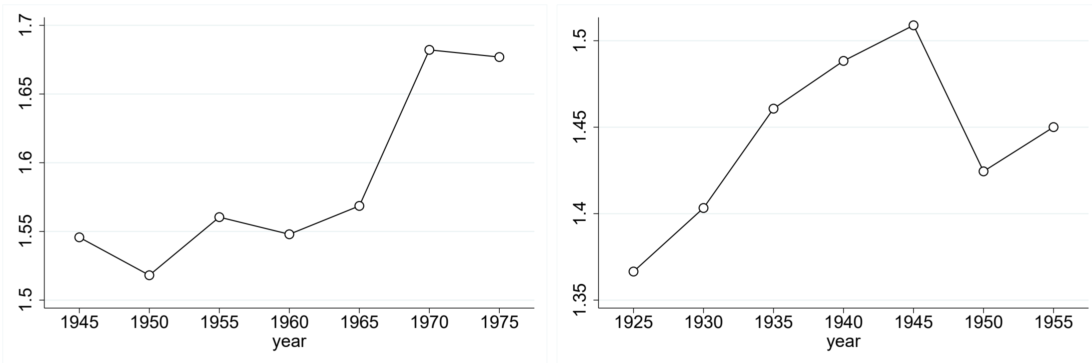


Figure A.2. Male Excess Mortality by Cohort

A. Age 45 B. Age 65

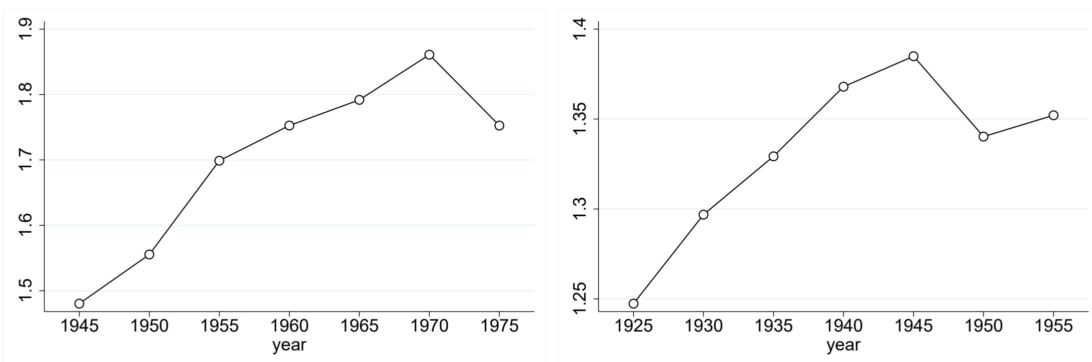


Figure A.3. Male Excess Mortality by Cohort: Census Data

A. Age 45 B. Age 65

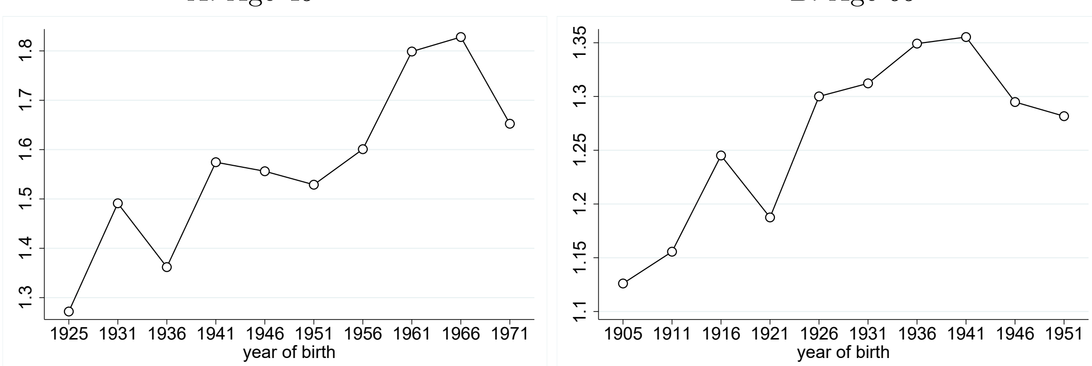
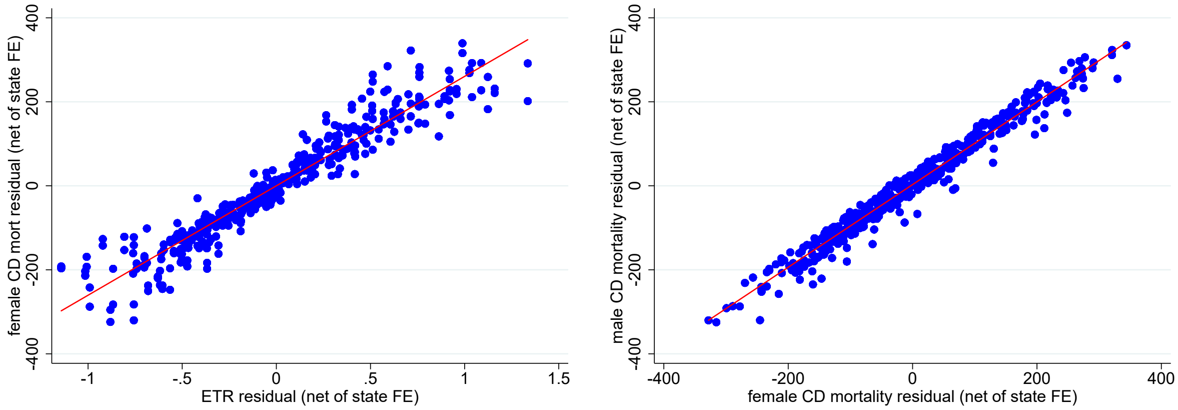


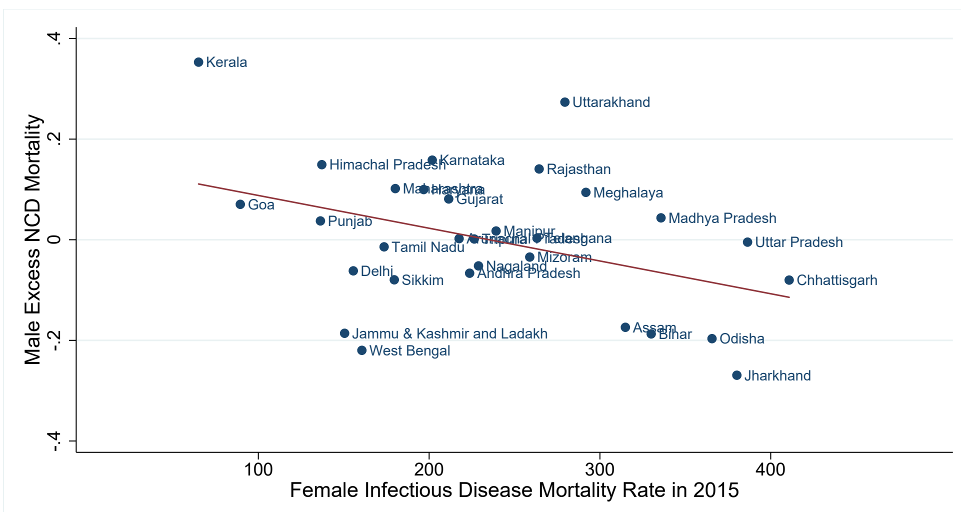
Figure A.1: estimates from regression of male excess NCD mortality at age 45 (Panel A) and age 65 (Panel B) on a full set of year dummies (omitting the regression constant). Figure A.2: estimates from regression of male excess mortality at age 45 (Panel A) and age 65 (Panel B) on a full set of year dummies (omitting the regression constant). Figure A.3: male excess mortality at age 45 (Panel A) and age 65 (Panel B), all India, Census data 1970–2016, Source: HLD (2025).

Figure A.4. Partial Correlations



Left: partial correlation between the epidemiological transition ratio (ETR) and the age standardized CD mortality for females, controlling for state fixed effects. Right: partial correlation between female and male CD mortality (age-standardized), controlling for state fixed effects.

Figure A.5. Female Infections Disease Mortality Rate and Male Excess NCD Mortality Ratio



The figure shows the state fixed effects from a regression of male excess NCD mortality on state and age fixed effects against the state-specific death rate from communicable diseases for females (age-standardized, per 100,000). The regression line is $0.153 - 0.0651 m_F^I$ where the mortality rate is measured in 1,000. Source IHME (2021).

Appendix D. Additional Results

Table A.1 Aging in India

	(1)	(2)	(3)	(4)
Gender	Women	Women	Men	Men
Age	0.142***	0.138***	0.148***	0.145***
	(0.000)	(0.001)	(0.000)	(0.000)
Constant	-3.523***	-3.489***	-3.651***	-3.623***
	(0.003)	(0.004)	(0.002)	(0.003)
Observations	3,150	3,030	3,150	3,030
R^2	0.970	0.986	0.971	0.984
State FE	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	No
Cohort FE	No	Yes	No	Yes

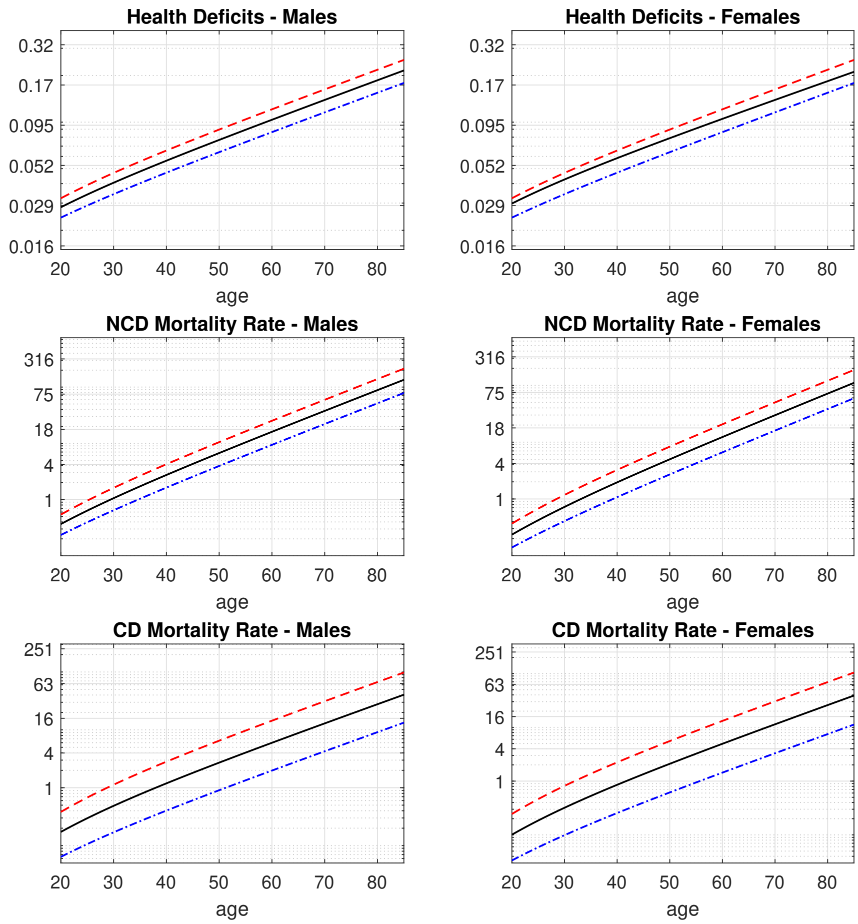
Source: Krenz and Strulik (2023). The table reports results from estimating equation (1). The dependent variable is the log of the frailty index (log deficits). The age variable takes a separate value for each age group (ages 20–25 to 90–94). Standard errors, clustered at state level, are reported in parenthesis; *** indicates statistical significance at the 1% level.

Table A.2. Frailty Index and NCD Mortality

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gender	Women	Women	Women	Women	Men	Men	Men	Men
log deficits	3.135***	3.137***	3.137***	2.051***	2.908***	2.909***	2.912***	1.668**
	(0.027)	(0.027)	(0.027)	(0.617)	(0.023)	(0.024)	(0.024)	(0.628)
Constant	9.493***	9.497***	9.497***	6.906***	9.491***	9.494***	9.501***	6.435***
	(0.053)	(0.064)	(0.064)	(1.472)	(0.055)	(0.058)	(0.058)	(1.547)
Observations	3,150	3,150	3,150	3,150	3,150	3,150	3,150	3,150
R^2	0.955	0.959	0.963	0.993	0.971	0.974	0.978	0.993
State FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	No	No	Yes	Yes
Age FE	No	No	No	Yes	No	No	No	Yes

Source: Krenz and Strulik (2023). The table reports results from estimating equation (2). The dependent variable is the log of the NCD mortality rate. Standard errors, clustered at state level, are reported in parenthesis; ** (***) indicates statistical significance at the 5% level (1% level).

Figure A.6. Calibrated Aging and Death of Men and Women



The Figure replicates the model predictions from Figure 5 for logarithmic scaling of deficits and mortality rates. Predicted health deficit accumulation, NCD mortality, and CD mortality for men and women for alternative paths of the epidemiological transition ratio (ETR), parameterized as $ETR = e_0 \exp(-0.035 \cdot t)$ where t is time in years and with $e_0 = 1.8$ (black solid lines), $e_0 = 2.4$ (red dashed lines), and $e_0 = 1.2$ (blue dotted lines). Age-group specific mortality rates are measured as deaths per 1,000.