Economic and Demographic Transition, Mortality, and Comparative Development

Matteo Cervellati Uwe Sunde

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Economic Transition:

- GDP *per capita* take-off after stagnation;
- Human capital formation: drastic change in the "education composition" of the population (from below 20 percent of individuals with some education to about 90 percent in few generations);
- (Structural Change: Agriculture-Industry)

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Demographic Transition:

- Increase in adult longevity (50-70 in few generations)
- Reduction in infant mortality (250 to 4 per thousand in few generations)
- Gross and net fertility (eventually) drop
  (from 6 child per woman to 2)
- Population growth despite decreases in fertility

Some Facts

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  1. Life expectancy at birth below 55 years;
  2. Average total fertility around 6 children per woman;
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  3. Share of population with at least completed secondary education below 20 percent.
- In 2000 40 percent of these countries had not exited the development trap yet.
- Most of these are countries in regions with large extrinsic mortality (due to e.g. tropical diseases, high density of pathogen species etc.)

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- What are the underlying forces behind transitions out of the development trap in these different dimensions?
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  - No available theory allows to analyze the economic and demographic dimensions in a unified framework delivering an endogenous transition.
- Why do some developing countries remain trapped in poor living conditions?
  - Since 1970 only a bit more than half of the developing countries have undergone the transition
- What is the role of mortality?
  - Ongoing empirical debate: we separately consider the implications of exogenous improvements (shocks) and structural differences in extrinsic mortality environment;

Contribution of this Paper

- Theory of Economic and Demographic Transition:
  - Endogenous change in mortality, fertility, education structure in population, gdp.
  - rationalize "difficult evidence": e.g. role of longevity for fertility, dynamic change in fertility and net fertility drop.

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- Theoretical investigation of the role of mortality for comparative development:
  - exogenous "shocks" to mortality (e.g. introduction of penicillin)
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- Theoretical investigation of the role of mortality for comparative development:
  - exogenous "shocks" to mortality (e.g. introduction of penicillin)
  - permanent differences in the mortality environment (e.g. tropical diseases)
- Compare theoretical implications with evidence from *time series* and *cross-country panel data*

Related Literature

Unified Growth Theories

- Change in fertility with quantity-quality trade-off [Galor and Weil, AER 2000, Galor and Moav, QJE 2002] (technical problems in including mortality)
- Exogenous mortality decline [Boldrin and Jones RED 2002, Boucekkine, de la Croix and Licandro, JET 2002, Soares, AER 2005]
- Endogenous mortality decline [Lagerlöf, IER 2003, Cervellati and Sunde, AER 2005, de la Croix and Licandro, mimeo 2007].
- Differential fertility and heterogenous human capital [de la Croix and Doepke, AER 2003, JDE 2004]

Related Literature (2)

Underdevelopment Traps and Comparative Development

- Poverty Traps [Azariadis and Stachurski, HANDBOOK EG 2005], Mortality Traps [Bloom and Canning, PNAS 2007]

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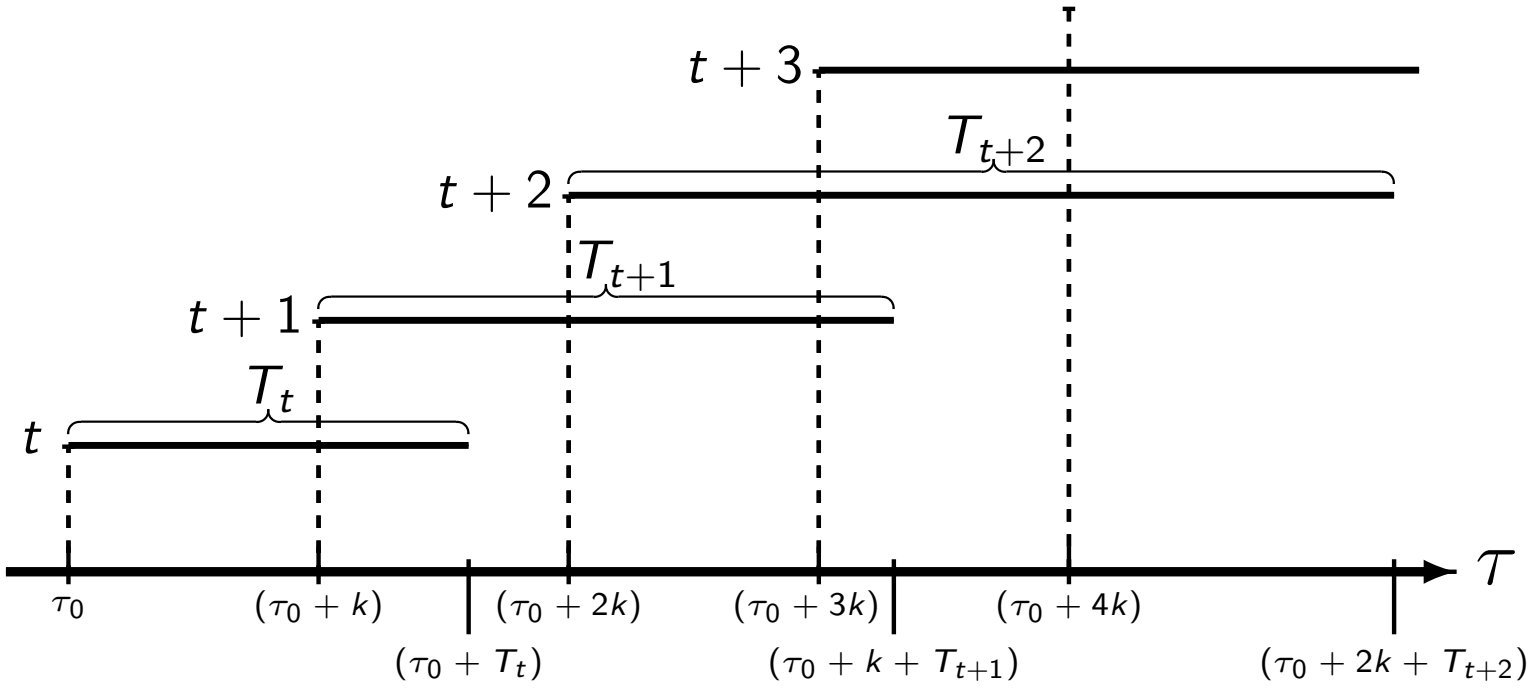
- Poverty Traps [Azariadis and Stachurski, HANDBOOK EG 2005], Mortality Traps [Bloom and Canning, PNAS 2007]
- Role of Mortality for development [Shastry and Weil, JEEA 2003, Soares, AER 2005, Weil, QJE 2007, Lorentzen et al., JEG 2008, Acemoglu and Johnson, JPE 2007];
- Debate "Geography vs. Institutions" [Acemoglu, Johnson and Robinson, AER 2001, Glaeser et al., JEG 2004, Rodrick et al., JEG 2004, Sachs, NBER 2003, (..)]

Set up

- Time is continuous, $\tau \in \mathbb{R}^+$
- Overlapping Generations of individuals $t \in \mathbb{N}^+$
- Frequency of Births k_t.
- Individual - generation specific - life expectancy T_t of adults, and child mortality $(1 - \pi_t)$
- Heterogeneous agents i with uniform *ex ante* distribution of abilities with $a^i \in [0, 1]$

Timing of Events



Preferences and Production Function

- Utility from *own* lifetime consumption c_t^i and well-being (potential income) of *offspring* y_{t+1}^i
- Preferences

$$u(c_t^i, y_{t+1}^i \pi_t n_t^i) = \left(c_t^i\right)^{(1-\gamma)} \left(y_{t+1}^i \pi_t n_t^i\right)^{\gamma} \text{ with } \gamma \in (0,1) \quad (1)$$

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- Unique consumption good produced with (vintage) aggregate production function.
- Aggregate production function:

$$Y_t = A_t \left[x_t \left(H_t^u\right)^{\eta} + (1 - x_t) \left(H_t^s\right)^{\eta}\right]^{\frac{1}{\eta}} \quad (2)$$

with $\eta \in (0,1)$ and the relative production share $x_t \in (0,1)$ $\forall t$.

Production of human capital

$$h^j\left(a^i, r_{t-1}, e_t\right) = \alpha^j\left(e_t - \underline{e}^j\right) f\left(r_{t-1}, \cdot\right) m^j(a^i) \tag{3}$$

with $h^j = 0\ \forall e < \underline{e}^j$ and $\underline{e}^s > \underline{e}^u \geq 0$, $\alpha^j > 0$, $j = u, s$.

- Education time (intensive margin) e_t;
- Investment of parents:

$$f\left(r_{t-1}, \cdot\right) \tag{4}$$

  with $f_r\left(.\right) > 0$ and $f_{rr}\left(.\right) < 0$.

- Ability:

$$m^j\left(a^i\right) \tag{5}$$

  with $m_r^j\left(a^i\right) \geq 0$ [simplify: $m^s\left(a\right) = a$ and $m^u\left(a\right) = 1$].

Individual Decision Problem

- **Total lifetime income** of individual i with ability a choosing human capital type j

$$y_t^{i,j}\left(a^i\right) = y_t^j\left(a^i, r_{t-1}^i, e_t^{i,j}\right) = w_t^j h^j\left(a^i, r_{t-1}^i, e_t^{i,j}\right)\left(T_t - e_t^{i,j}\right) \quad (6)$$

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- **Individual Problem:** Choose type $j = u, s$ and time of *own* education $e_t^{i,j}$, gross fertility n^i, and time spent in raising children r_t:

$$\left\{j^*, e_t^{i,j*}, n_t^{i,j*}, r_t^{i*}\right\} = \underset{\left\{n_t, r_t, , e_t^j, j=u,s\right\}}{\arg\max} \; u_t\left(c_t^i, \pi_t n_t^{i,j} y_{t+1}^j\left(a^i, r_t^i, e_{t+1}^{i,j}\right)\right) \quad \text{(P1)}$$

subject to:

$$c_t^i = w_t^j h_t^j\left(a^i, r_{t-1}^i, e_t^{i,j}\right)\left(T_t\left(1 - r_t^i \pi_t n_t^{i,j}\right) - e_t^j\right)$$

and to (6) for $j = u, s$.

Partial Equilibrium: Individual Education and Fertility

Proposition

[Individual Education and Fertility] *For any* $\left\{w_t^j, T_t, \pi_t\right\}$, *the vector of an individual's optimal education, fertility and time devoted to his children,* $\left\{e_t^{j*}, n_t^{j*}, r_t^*\right\}$, *given that the individual acquires human capital of type* $j = \{u, s\}$, *is given by,*

$$e_t^{i,j*} = e_t^{j*} = \frac{T_t(1-\gamma) + \underline{e}^j}{(2-\gamma)}, \tag{7}$$

$$n_t^{i,j*} = n_t^{j*} = \frac{\gamma}{2-\gamma}\frac{T_t - \underline{e}^j}{T_t r_t^* \pi_t} \quad \text{and} \tag{8}$$

with r_t^* *solving,*

$$\varepsilon_{f,r} \equiv \frac{\partial f\left(r_t^i, \cdot\right)}{\partial r_t^i}\frac{r_t^i}{f\left(r_t^i, \cdot\right)} = 1 \tag{9}$$

General Equilibrium (Intra-generational)

$\Longrightarrow$ Wages?

- Aggregate levels of human capital supplied by generation t:

$$H_t^u\left(\widetilde{a}_t\right) = \int_0^{\widetilde{a}_t} h_t^u(a) d(a) da \qquad \text{and} \qquad H_t^s\left(\widetilde{a}_t\right) = \int_{\widetilde{a}_t}^1 h_t^s(a) d(a) da \tag{10}$$

- Wage rates are determined on competitive labor markets:

$$w_t^s = \frac{\partial Y_t}{\partial H_t^s} \quad \textit{and} \quad w_t^u = \frac{\partial Y_t}{\partial H_t^u}$$

with,

$$\frac{w_t^u}{w_t^s} = \frac{x_t}{1-x_t}\left(\frac{H_t^s\left(\widetilde{a}_t\right)}{H_t^u\left(\widetilde{a}_t\right)}\right)^{1-\eta} \tag{11}$$

General Equilibrium (Intra-generational)

Proposition

[Human Capital Investment in Equilibrium] *For any generation* t*, and for any given* $\{T_t, \pi_t, A_t, x_t\}$ *there exists a unique*

$$\lambda_t \equiv 1 - \widetilde{a}_t^*$$

and accordingly a unique vector, $\left\{H_t^{j*}, w_t^{j*}, r_t^*, e_t^{j*}, n_t^{j*}, h^{j*}(a)\right\}$ *for each* $a \in [0,1]$ *and* $i = u, s$*, which solves the individual problem (P1) for each individual, consistent with wages given in* (11)*, where*

$$\lambda_t = \Lambda(T_t, x_t)\,, \tag{12}$$

is an increasing, S-shaped function of expected lifetime duration T_t*, with zero slope for* $T \longrightarrow 0$ *and* $T \longrightarrow \infty$*.*

Dynamics: Mortality

- *Child Survival Rate (Child Mortality)*

$$\pi_t = \Pi\left(H^{s+}_{t-1}, y^{+}_{t-1}\right) \tag{13}$$

with $\Pi(0, H^s_0) = \underline{\pi}$.

- *Adult Longevity*

$$T_t = \Upsilon\left(H^{s+}_{t-1}, y^{+}_{t-1}\right) \tag{14}$$

with $\Upsilon(0) > 0$ and $\Upsilon(1) < \infty$ and $\lim_{y_t \to \infty} \partial T_t / \partial y_{t-1} = 0$ where $y_{t-1} = Y_{t-1}/N_{t-1}$.

Dynamics: Technological Progress

Skill-biased technical change

$$g_t = \frac{A_t - A_{t-1}}{A_{t-1}} = F\left(\widetilde{a}_t^*, A_{t-1}\right) = \delta H_{t-1}^s(H_{t-1}^s)A_{t-1} \tag{15}$$

where $\delta > 0$, and

$$x_t = X\left(A_t\right) \text{ with } \frac{\partial X\left(A_t\right)}{\partial A_t} < 0 \tag{16}$$

$\longrightarrow$ instrumental assumption!

Development Dynamics of the Economy

Evolution of the non linear dynamic system:

$$\begin{cases} \lambda_t &= \Lambda(T_t, x_t) \\ T_t &= \Upsilon(\lambda_{t-1}) \\ \pi_t &= \Pi(\lambda_{t-1}, T_{t-1}, x_{t-1}) \\ x_t &= X(\lambda_{t-1}, T_{t-1}, x_{t-1}) \end{cases} \tag{17}$$

Evolution of Conditional Dynamic System

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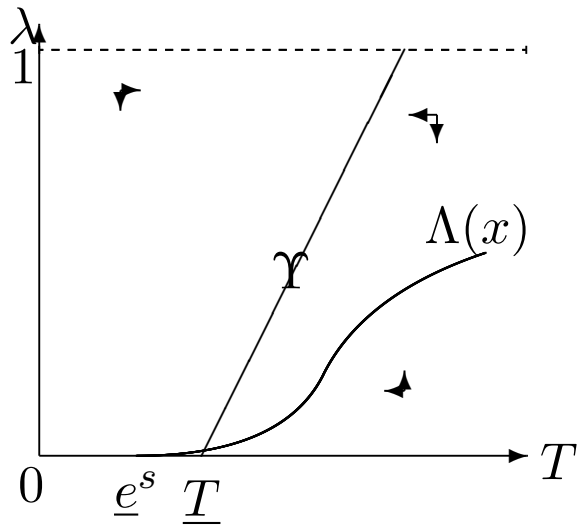
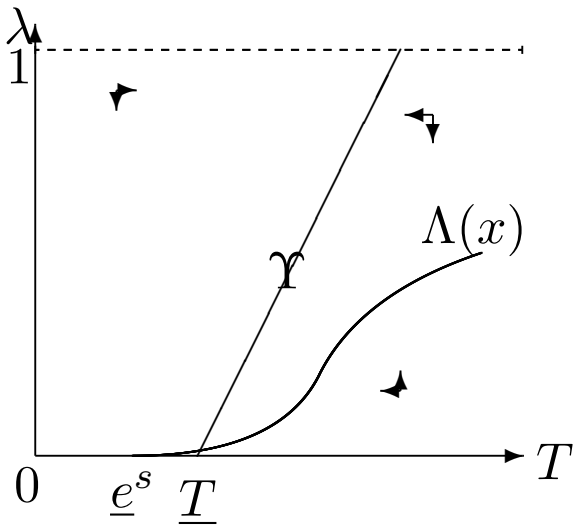


(a)

Evolution of Conditional Dynamic System



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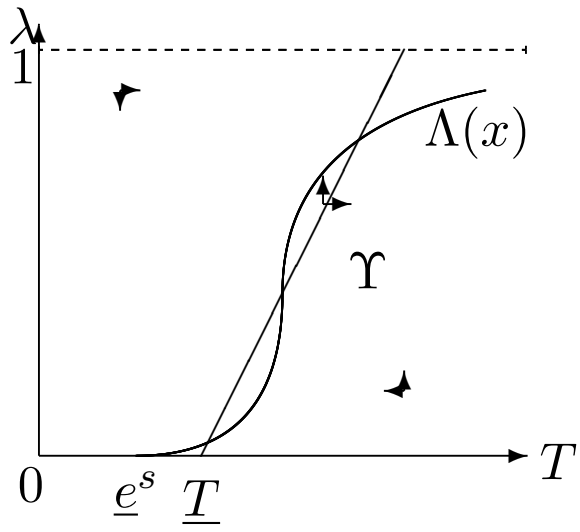
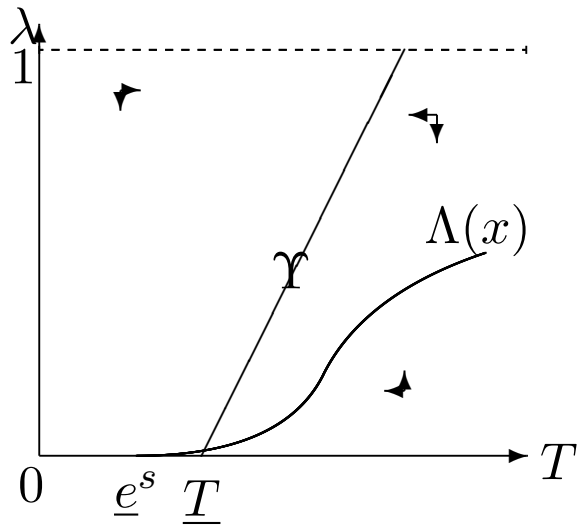


(b)

Evolution of Conditional Dynamic System



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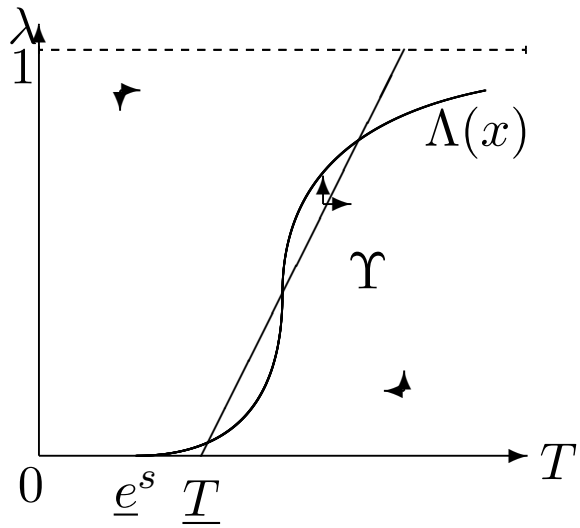

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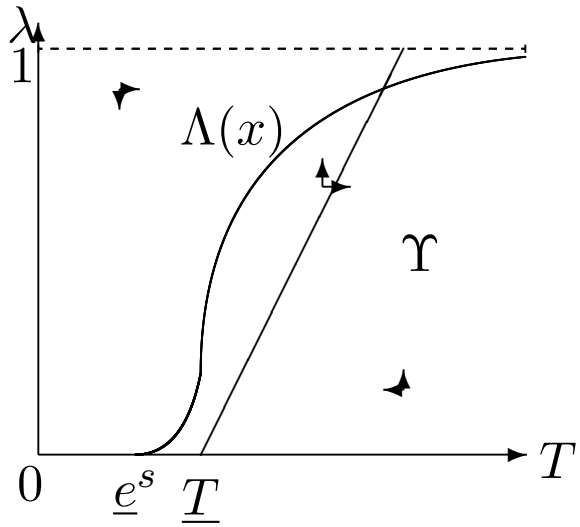

Time Series Predictions

Proposition

[Economic and Demographic Transitions] *The economy is characterized by the following phases in the process of development:*

(i) A (potentially very long) phase of stagnant development with little technological change, low longevity, $T_0 \simeq \underline{T}$*, large child mortality* $\pi_0 = \underline{\pi}$*, very few individuals acquiring human capital* h^s*,* $\lambda_0 \simeq 0$ *and large gross and net fertility rates;*

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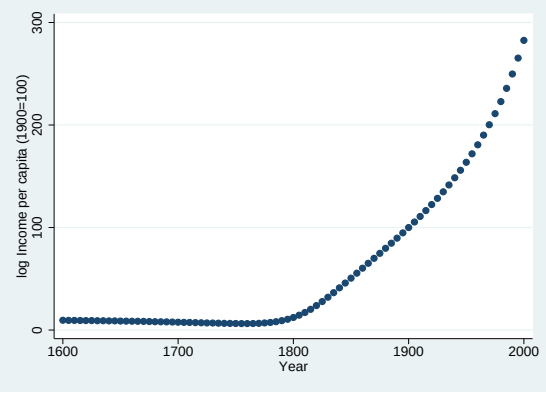
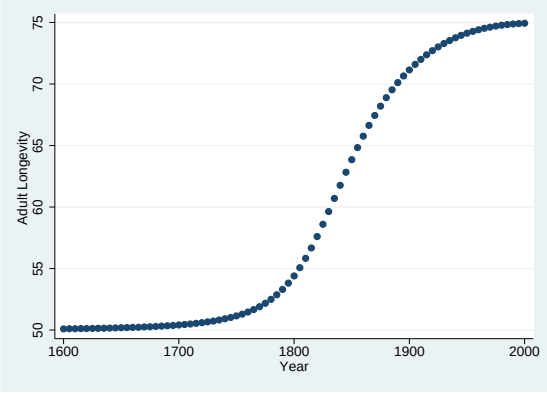
(ii) A rapid transition involving rapid increase in T_t*,* π_t*,* λ_t *income per capita* y_t *and technological level* A_t *and a reduction in net fertility (possibly following an initial temporary increase);*

(iii) A phase of significant permanent growth in technology and income with large life expectancy $T_\infty \simeq \underline{T} + \rho$*, negligible child mortality* $\pi_\infty \simeq 1$ *all population acquiring* h^s *human capital* $\lambda_\infty \simeq 1$ *and low gross and net fertility rates.*

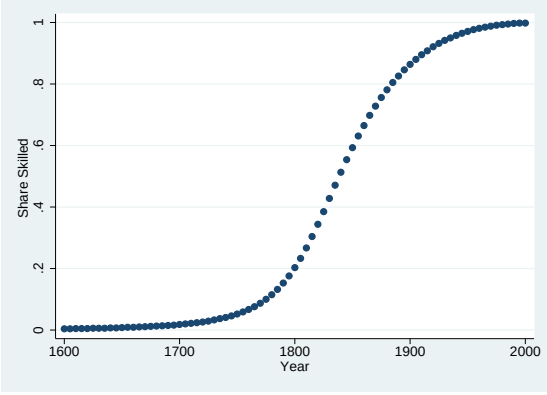
Time Series Predictions: A Simulation of the Development Process



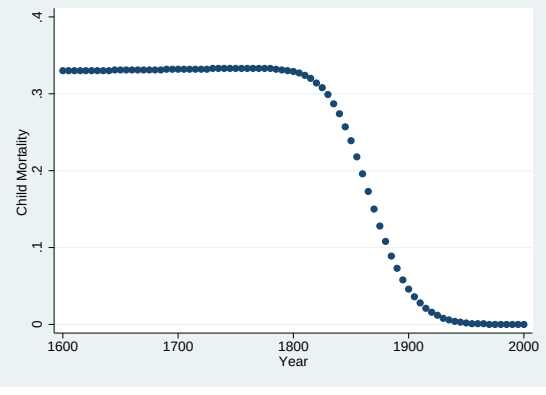
(a) log GDP per capita ($\ln y$)



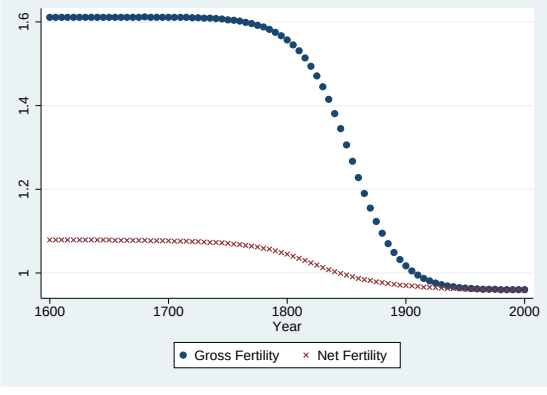
(b) Adult Life Expectancy (T)



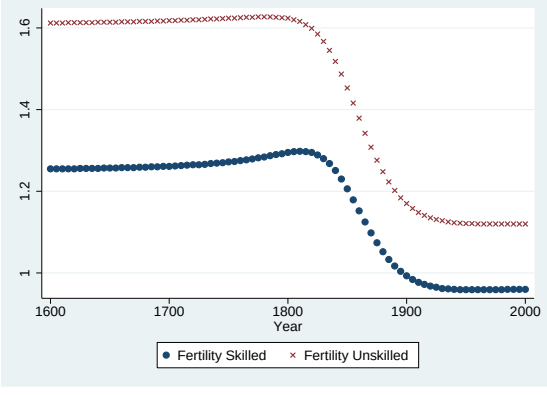
(c) Share Skilled (λ)



(d) Child Mortality

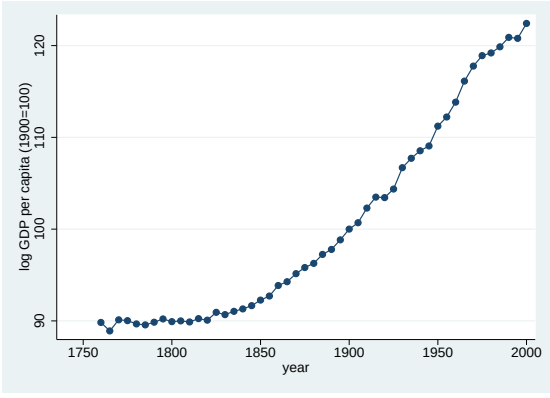


(e) Gross and Net Reproduction Rates (n, πn)

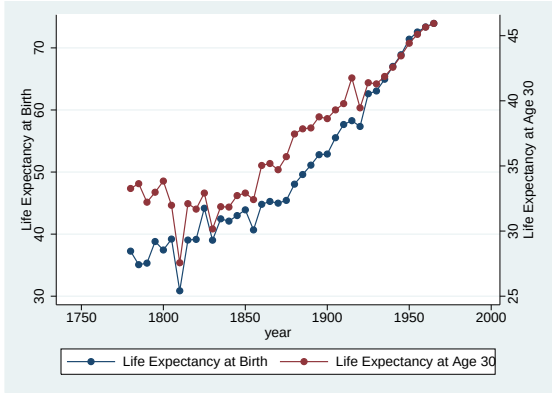


(f) Differential Fertility (n_H, n_L)

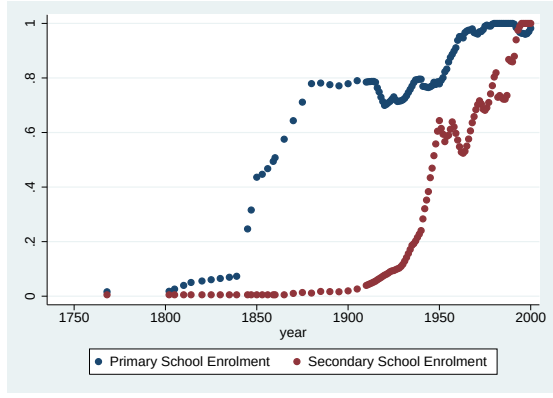
Time Series Data: Long-Run Development for Sweden



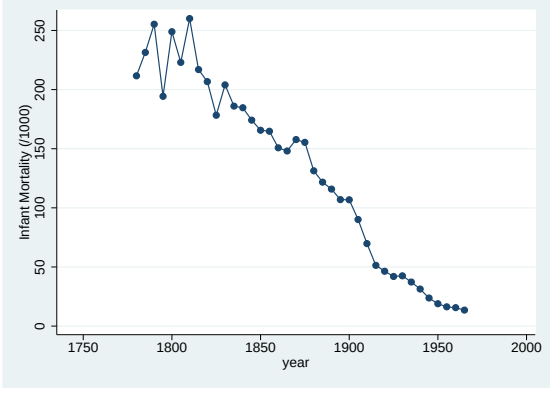
(a) log GDP per capita



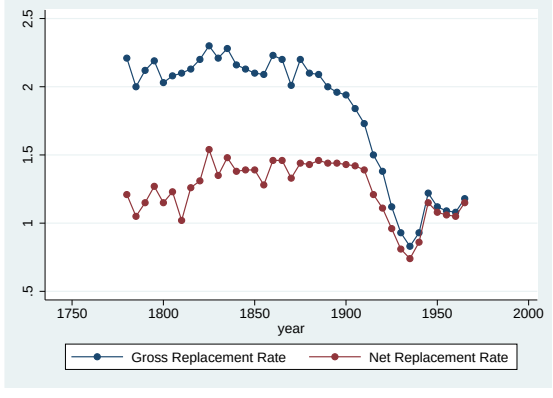
(b) Life Expectancy at Birth and at Age 30



(c) Primary and Secondary School Enrolment

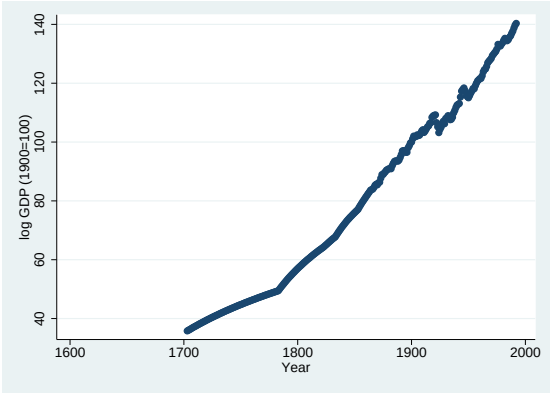


(d) Infant Mortality Rate

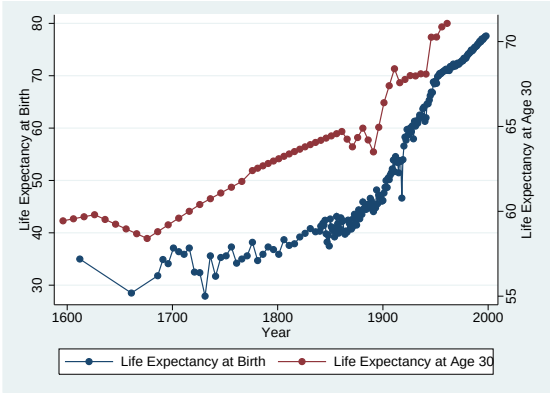


(e) Gross and Net Reproduction Rates

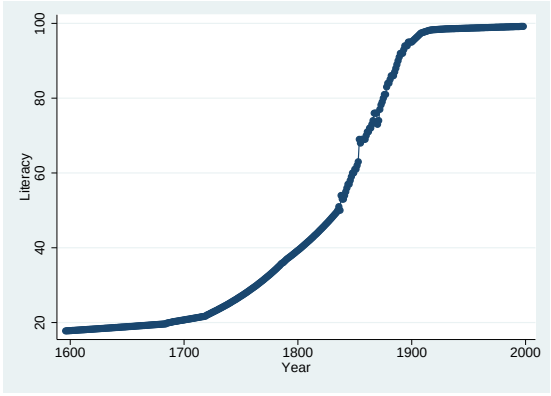
Time Series Data: Long-Run Development for England



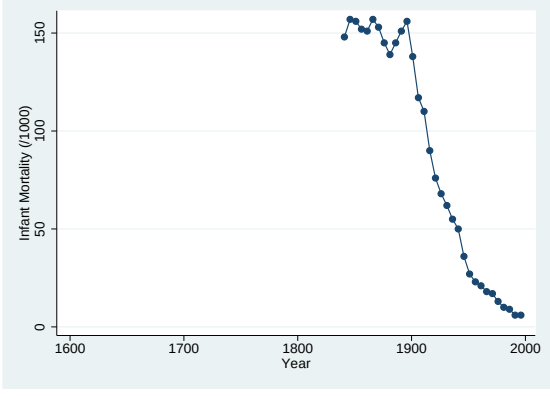
(g) log GDP per capita (U.K.)



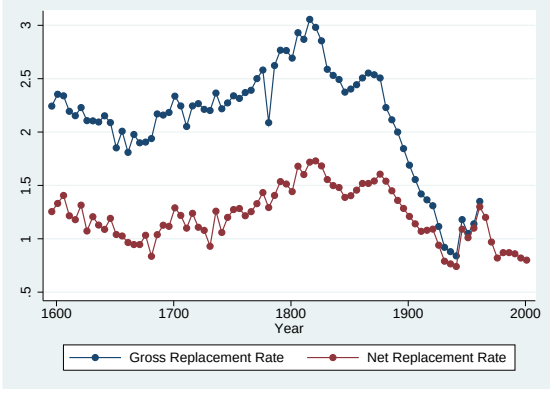
(h) Life Expectancy at Birth and at Age 30



(i) Literacy Levels (England and Wales)



(j) Infant Mortality Rate



(k) Gross and Net Reproduction Rates (England and Wales)

Cross-Sectional Predictions

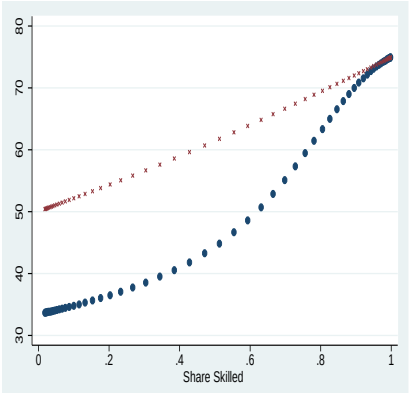
- The transition is driven by, and leads to, a change in "education composition" in the population;

Corollary

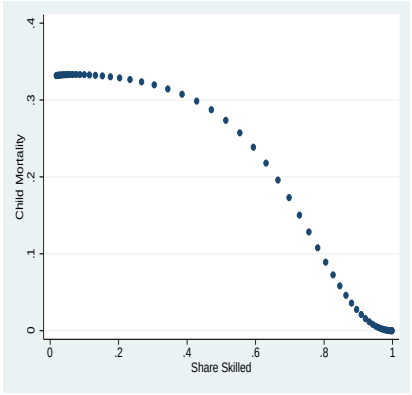
There is a positive contemporaneous correlation between λ_t and life expectancy (T_t and π_t) over the course of development, and overall a negative contemporaneous correlation of λ with gross and net fertility.

Cross-Sectional Predictions:

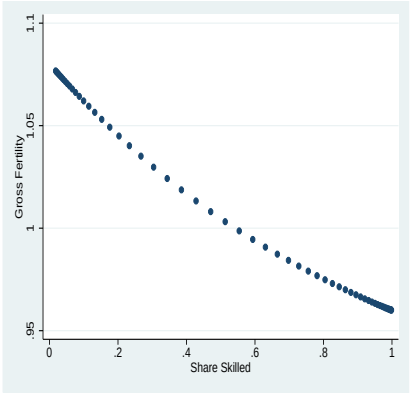
Simulated data (reinterpreted cross-sectionally) and Data



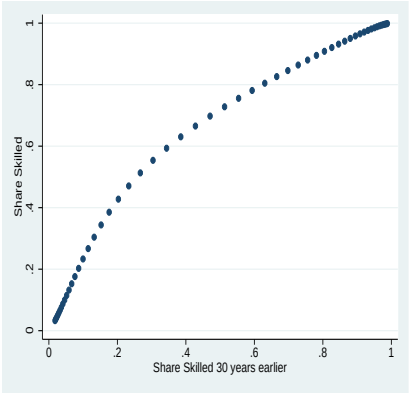
(a) Adult Longevity (x), LEB (o), λ



(b) Child Mortality, λ



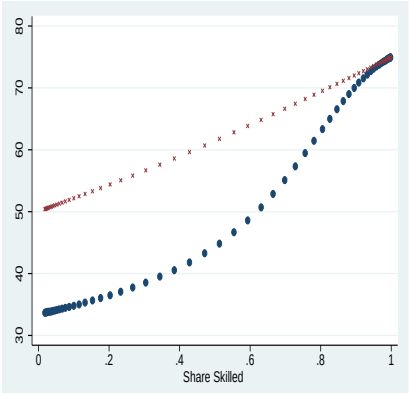
(c) Av. Fertility, λ



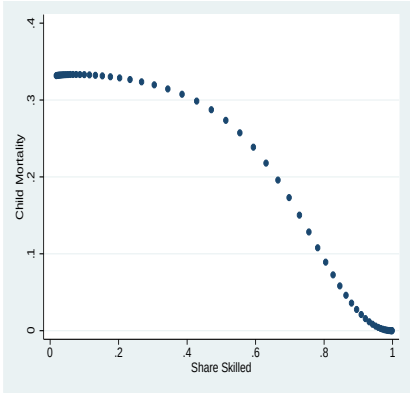
(d) λ_t, λ_{t-n} (n=30 yrs.)

Cross-Sectional Predictions:

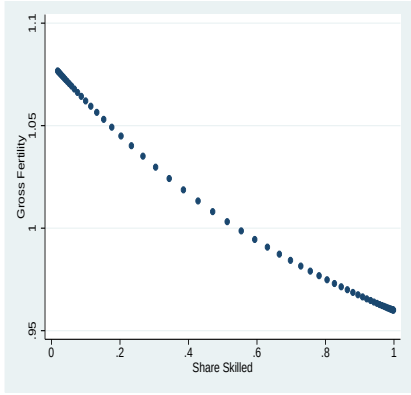
Simulated data (reinterpreted cross-sectionally) and Data



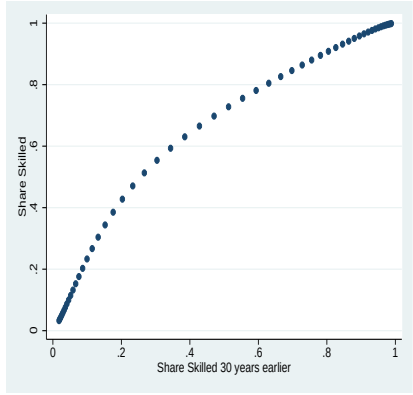
(a) Adult Longevity (x), LEB (o), λ



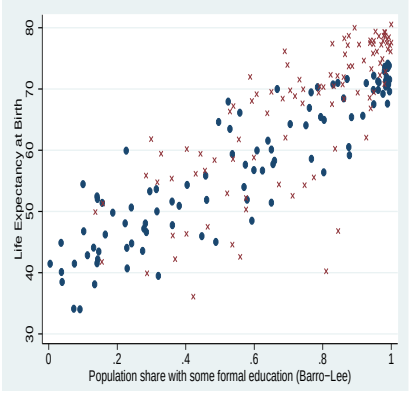
(b) Child Mortality, λ



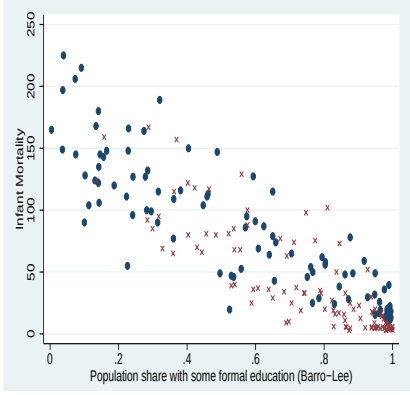
(c) Av. Fertility, λ



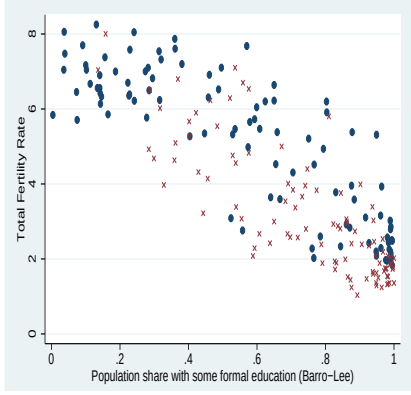
(d) λ_t, λ_{t-n} (n=30 yrs.)



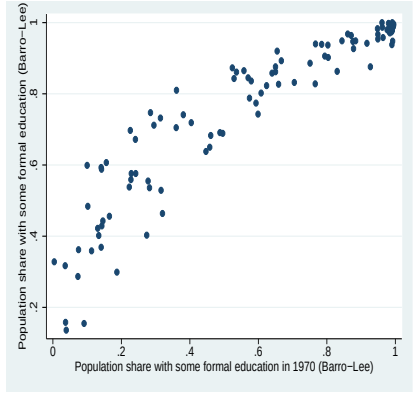
(e) LEB, λ , 1970 (o) and 2000 (x)



(f) Child Mortality, λ , 1970 (o) and 2000 (x)



(g) TFR, λ , 1970 (o) and 2000 (x)



(h) λ 1970 and 2000

Role of Mortality:

Adult Longevity and Changes in Education Composition

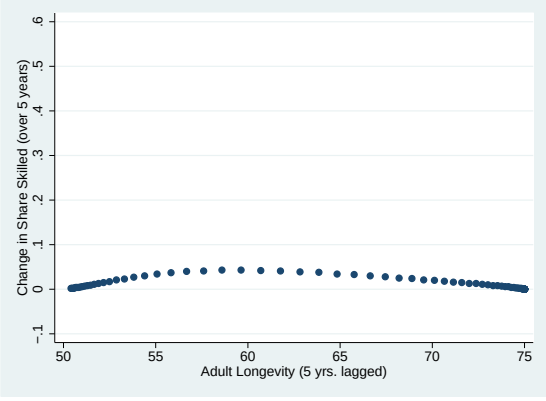
- The change in education composition depends on the "initial level" of longevity:

Corollary

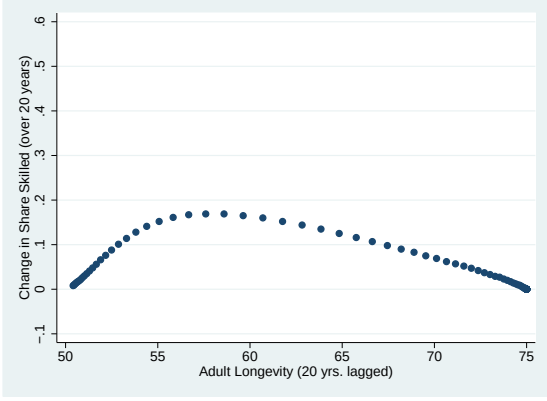
- *Along the development path, the correlation between longevity and the subsequent change in the education composition is hump-shaped.*
- *The longer the time horizon for subsequent changes in the education composition, the more pronounced is the hump and the lower is the longevity associated with the largest subsequent changes (the peak in the hump).*

Role of Mortality:

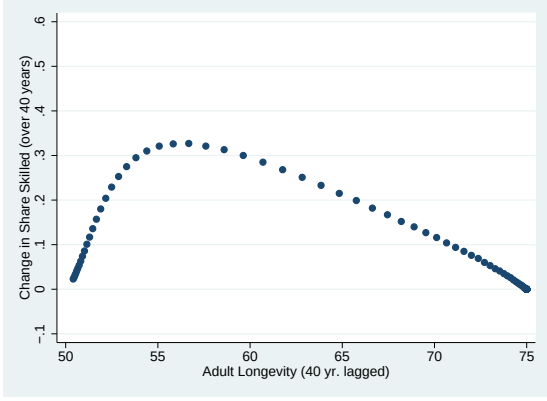
Adult Longevity and Changes in Education Composition



(a) Change in λ over 5 years



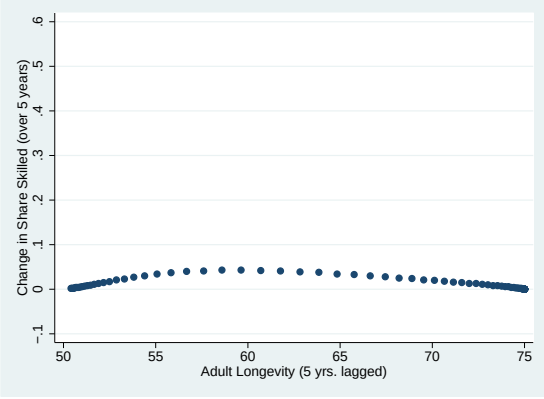
(b) Change in λ over 20 years



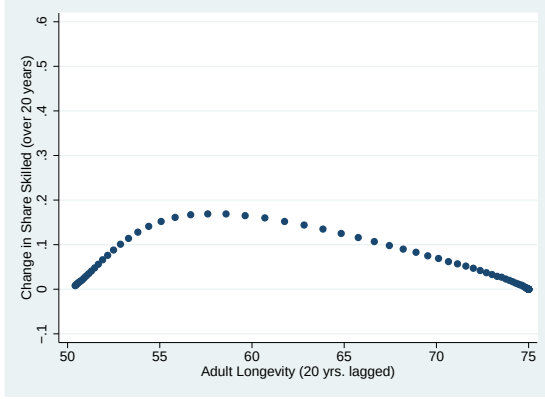
(c) Change in λ over 40 years

Role of Mortality:

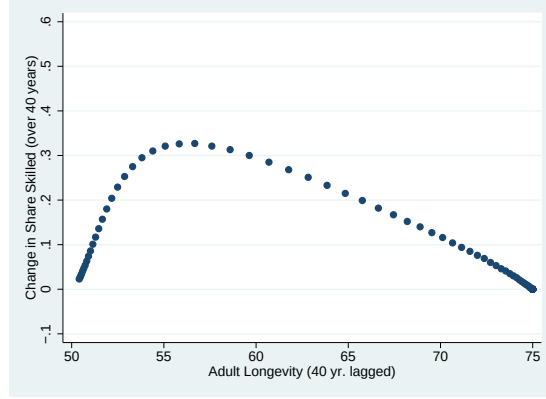
Adult Longevity and Changes in Education Composition



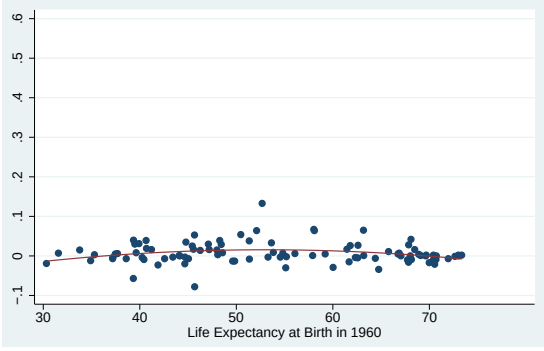
(a) Change in λ over 5 years



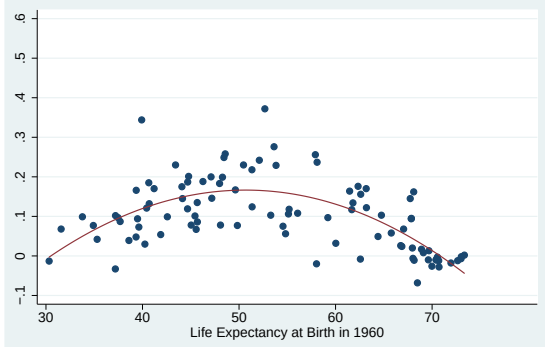
(b) Change in λ over 20 years



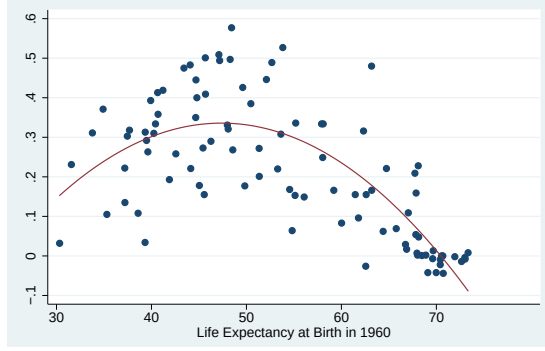
(c) Change in λ over 40 years



(d) Change in λ over 5 years(1960-1965)



(e) Change in λ over 20 years (1960-1980)



(f) Change in λ over 40 years (1960-2000)

Role of Mortality:

Exogenous Improvements and Shocks

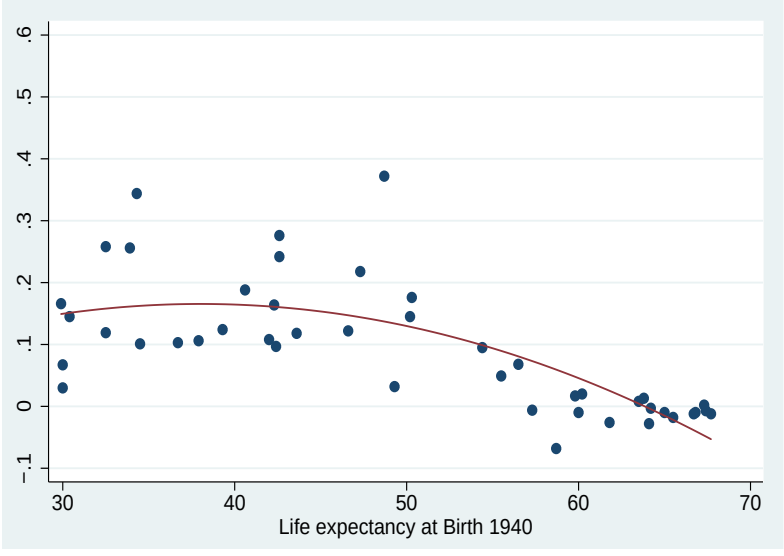
Corollary

The effect on education of an exogenous increase in longevity has an inverse U-shape.

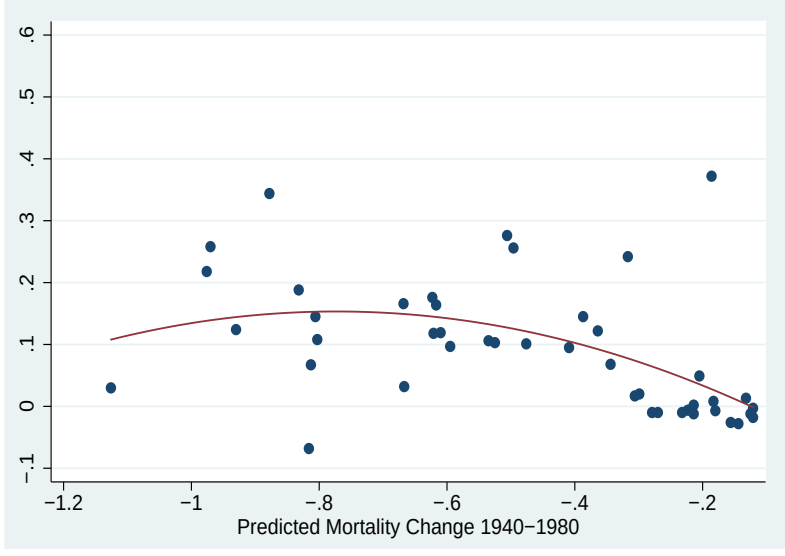
- Data from Acemoglu and Johnson (2007) on predicted mortality changes following the "epidemiological" revolution in the 1940's.

Role of Mortality:

Exogenous Improvements and Shocks



(a) LEB (1940) andchange in λ (1960-1980)



(b) Pred Mortality change 1940-1980 and change in λ (1960-1980)

Role of Mortality:

Permanent differences in Extrinsic Mortality Environment

- "Extrinsic" Mortality varies substantially across countries and is related to geographical characteristics [Brown MACROECOLOGY(1995), Gallup et al. IRSR (1999), Guernier et al PLOS BIOLOGY (2004)]

Corollary

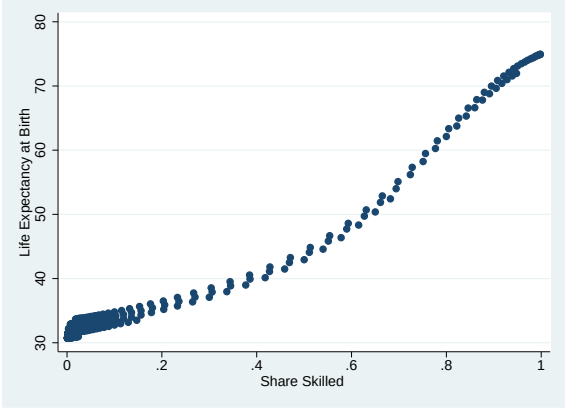
A lower baseline adult longevity, $\underline{T}$ implies (ceteris paribus:

- *a later onset of the transition;*
- *a higher level of economic development in terms of income or productivity at the onset of the transition.*

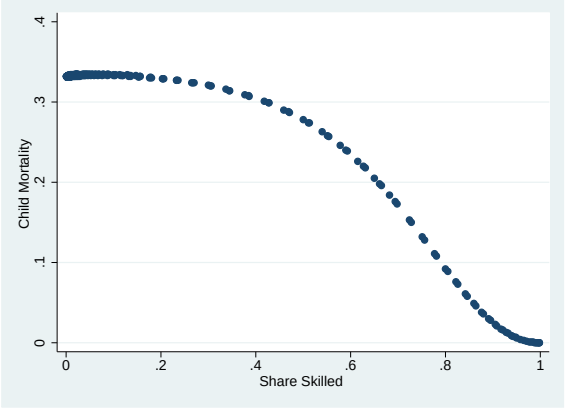
Role of Mortality:

Permanent differences in Extrinsic Mortality Environment

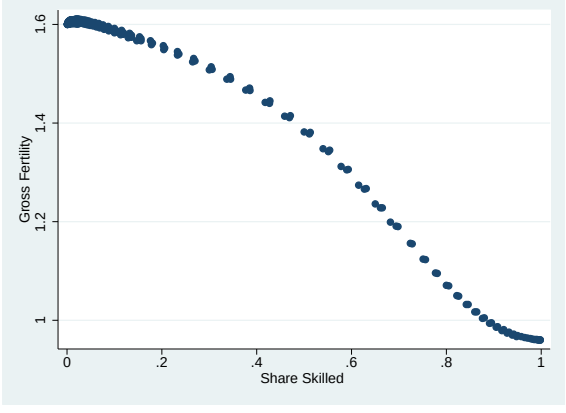
Cross-sectional implications ($\underline{T} \in \{46, 47, 48, 49, 50\}$)



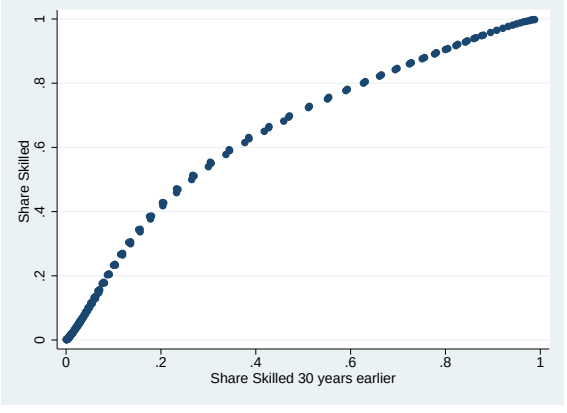
(a) Adult Life Expectancy and λ



(b) Child Mortality and λ



(c) Average Fertility and λ

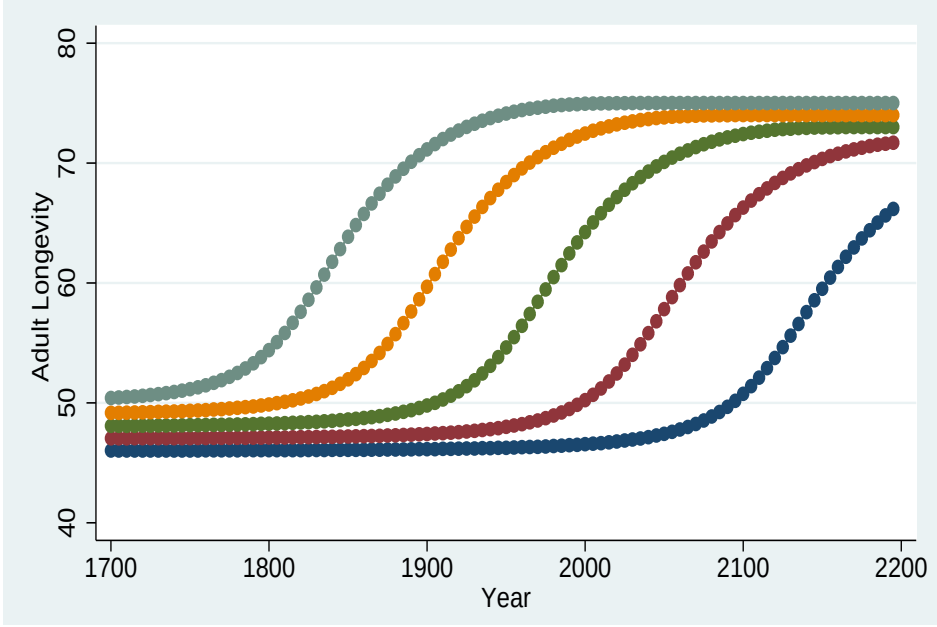


(d) λ_t and λ_{t-n} (n=30 yrs.)

Role of Mortality:

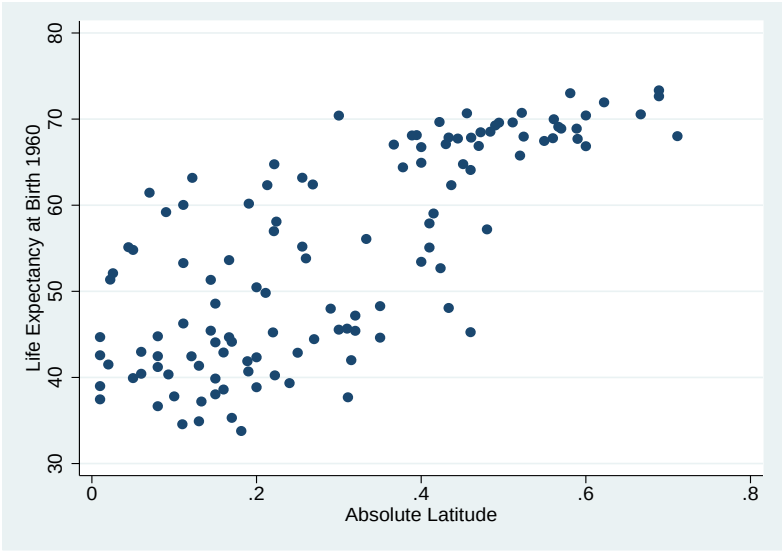
Permanent differences in Extrinsic Mortality Environment

Timing of Transition ($\underline{T} \in \{46, 47, 48, 49, 50\}$)

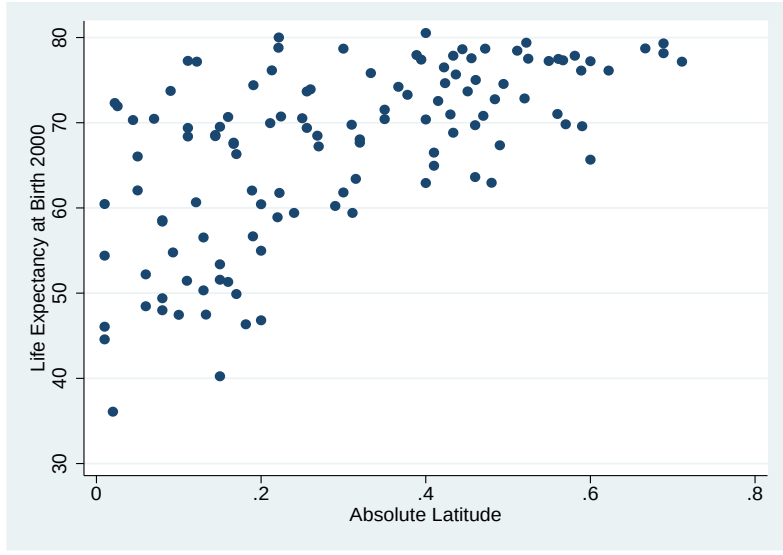


Delay in onset of transition due to differences in baseline longevity.

Geography and Mortality: Latitude



(a) LEB and latitude (1960)



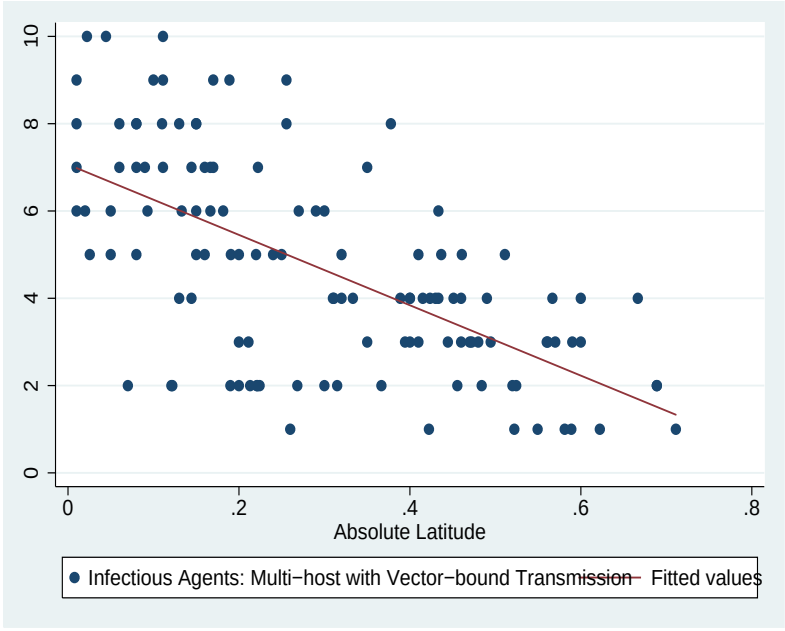
(b) LEB and latitude (2000)

Geography and Mortality: Infectious Disease Richness

Multi-host vector-transmitted infectious agents are very localized and little affected by globalization and development
(Smith et al., ECOLOGY 2007).

Geography and Mortality: Infectious Disease Richness

Multi-host vector-transmitted infectious agents are very localized and little affected by globalization and development
(Smith et al., ECOLOGY 2007).

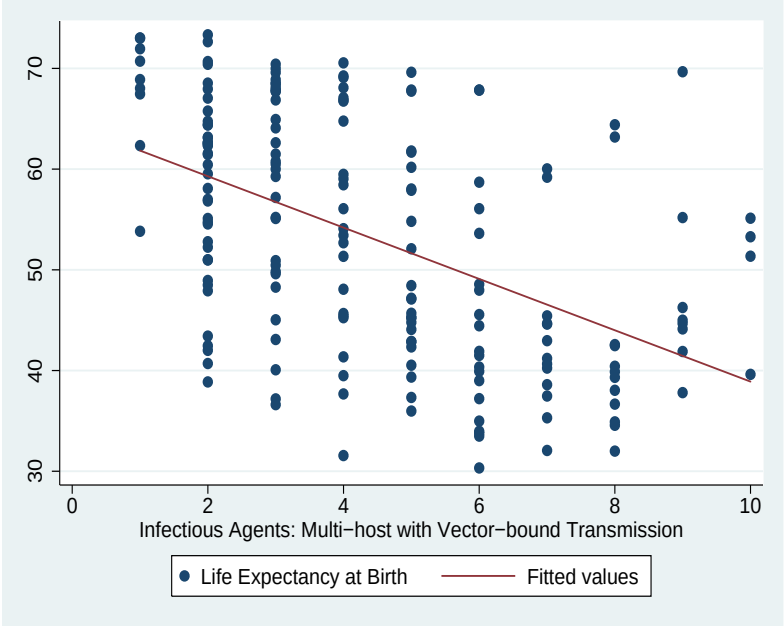


(a) Infectious Disease Richness and latitude

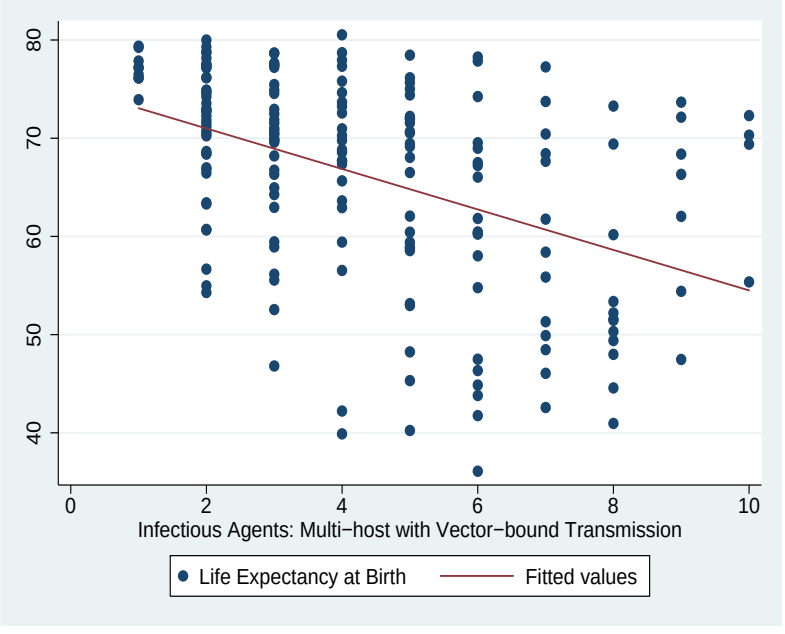
[Multi-Host Vector Transmitted Diseases: Angiomatosis, Relapsing Fever, Typhus-epidemic, Trypanosomiasis (sleeping sickness), Filariasis, Leishmaniasis, Yellow Fever, Dengue, Onchocerciasis, (...)]

Geography and Mortality: Infectious Disease Richness

Multi-host vector-transmitted infectious agents
and Life Expectancy at Birth 1960-2000



(a) Infectious Disease Richness and LEB (1960)



(b) Infectious Disease Richness and LEB (2000)

Cross-Sectional Predictions over Time:

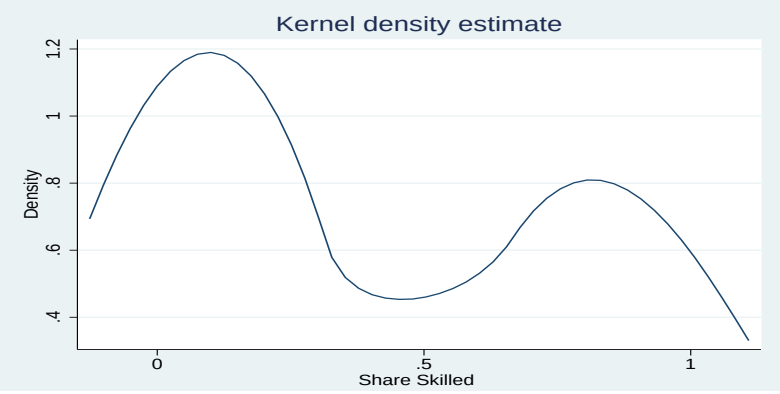
Bi-modal world distributions of mortality, fertility and education

Corollary

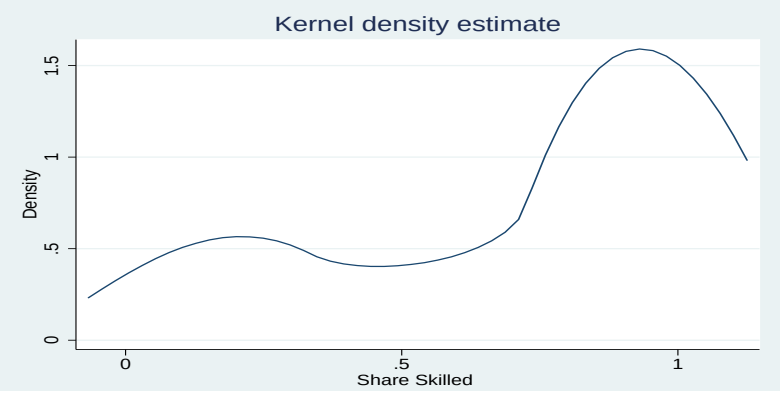
The cross-sectional distributions of adult longevity, child mortality, fertility and education are bi-modal, unless all countries are trapped or have completed the transition.

Cross-Sectional Predictions over Time:

Share of agents with Some Education (81 countries, $\underline{T} \in [46, 50]$)



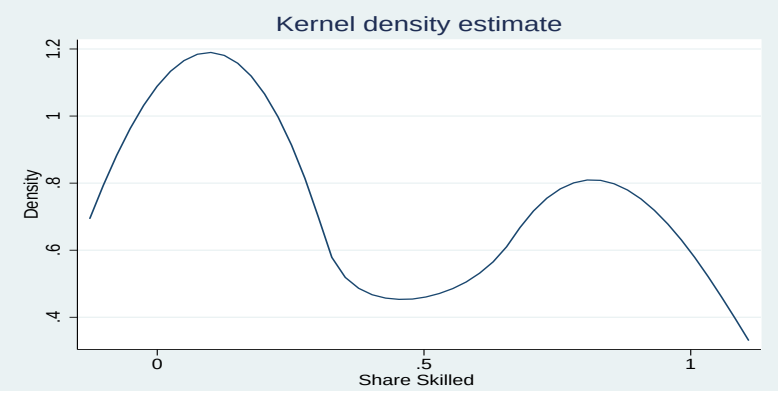
(a) Share Skilled (λ) (1950)



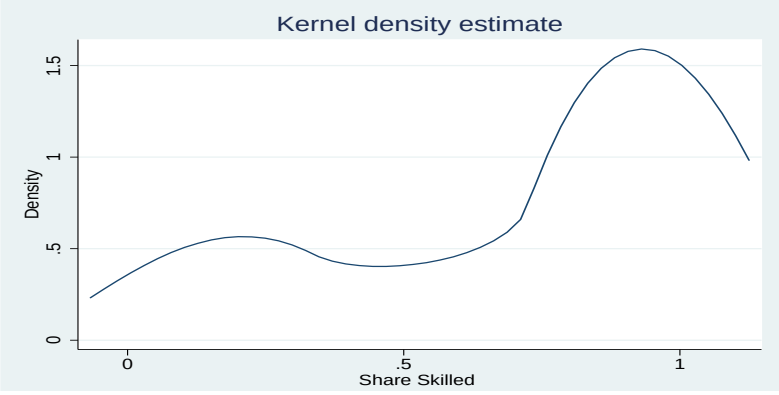
(b) Share Skilled (λ) (2050)

Cross-Sectional Predictions over Time:

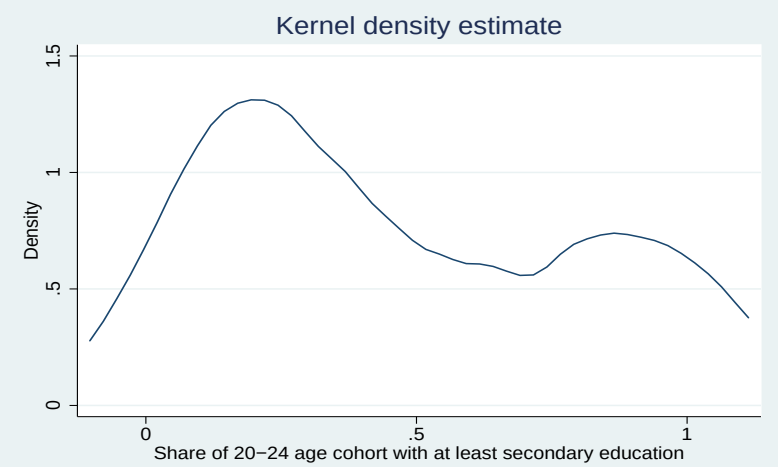
Share of agents with Some Education (81 countries, $\underline{T} \in [46, 50]$)



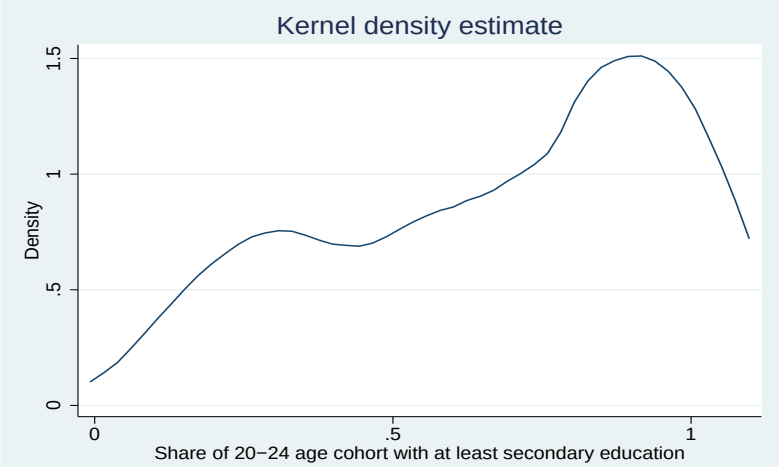
(a) Share Skilled (λ) (1950)



(b) Share Skilled (λ) (2050)



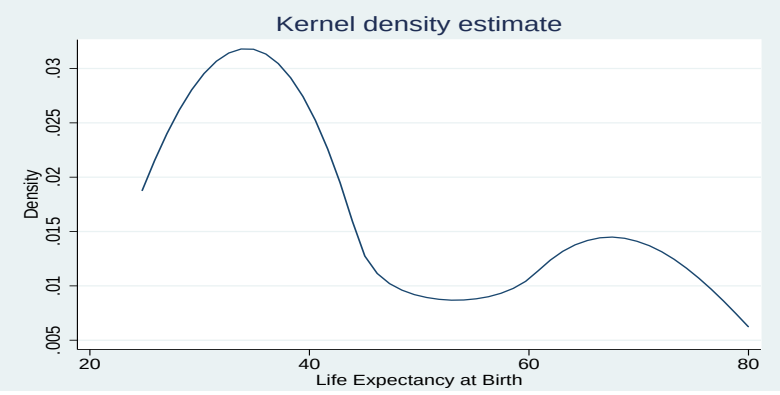
(c) Share with at least some schooling 1970



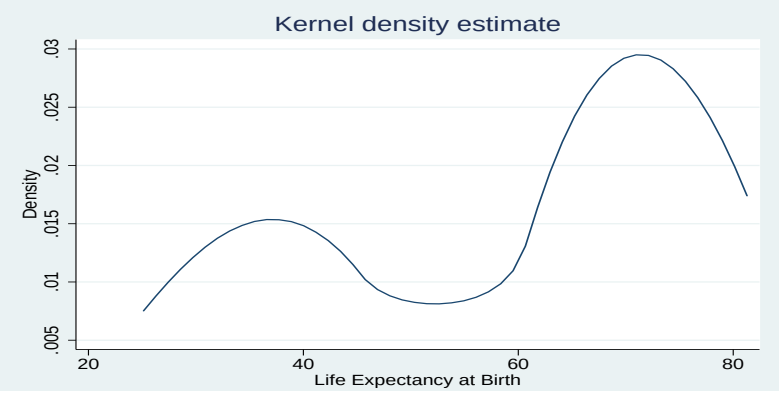
(d) Share with at least some schooling 2000

Cross-Sectional Implications:

Life Expectancy at Birth (81 countries, $\underline{T} \in [46, 50]$)



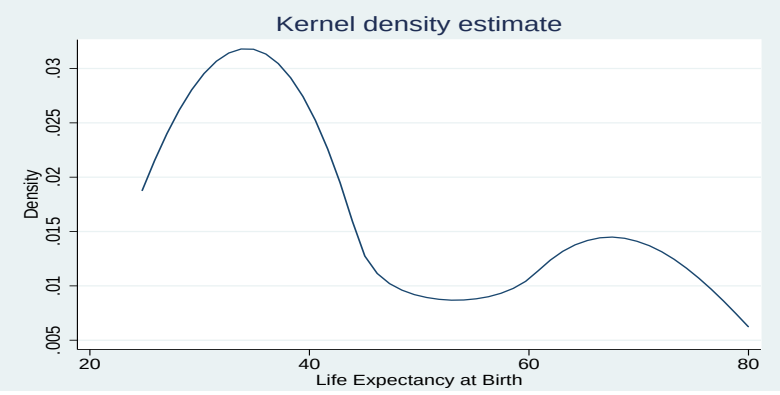
(a) Life Expectancy at Birth (1950)



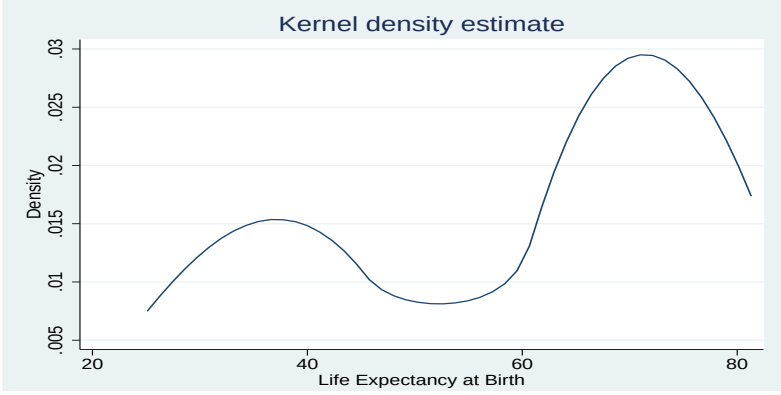
(b) Life Expectancy at Birth (2050)

Cross-Sectional Implications:

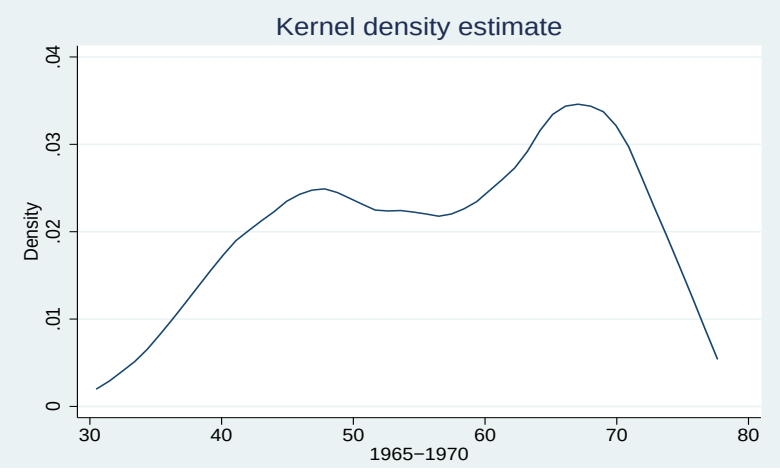
Life Expectancy at Birth (81 countries, $\underline{T} \in [46, 50]$)



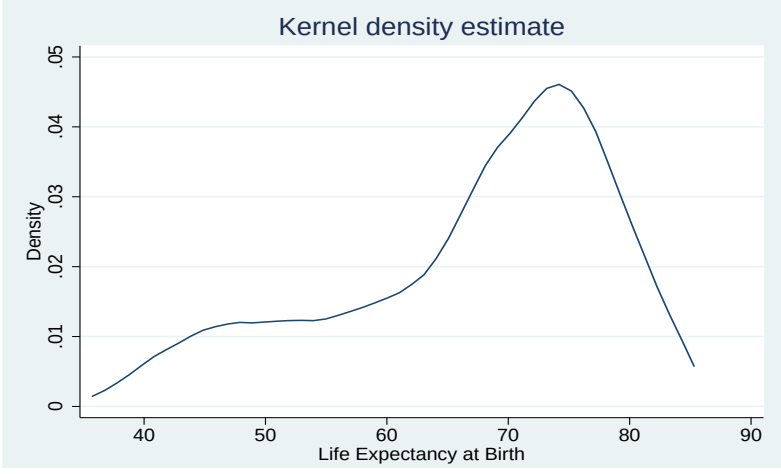
(a) Life Expectancy at Birth (1950)



(b) Life Expectancy at Birth (2050)



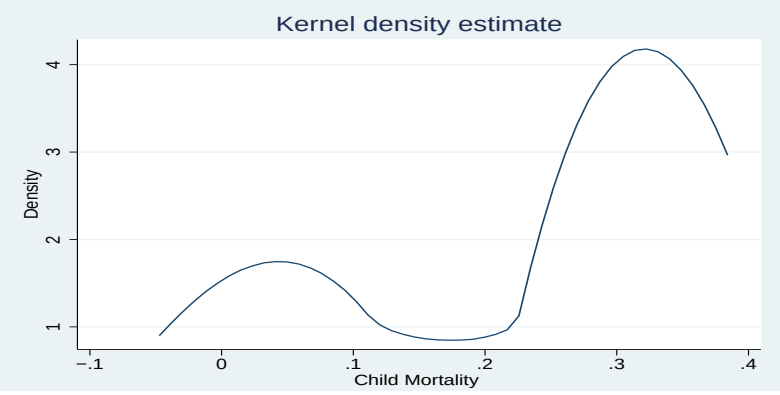
(c) Life Expectancy at Birth 1965-1970



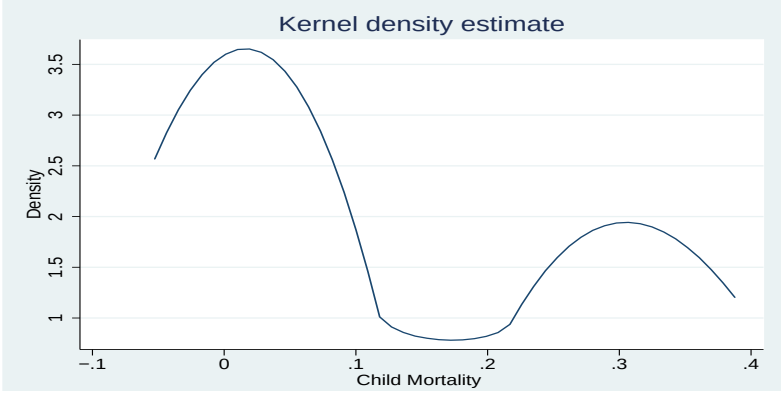
(d) Life Expectancy at Birth 2000-2005

Cross-Sectional Implications:

Child Mortality (81 countries, $\underline{T} \in [46, 50]$)



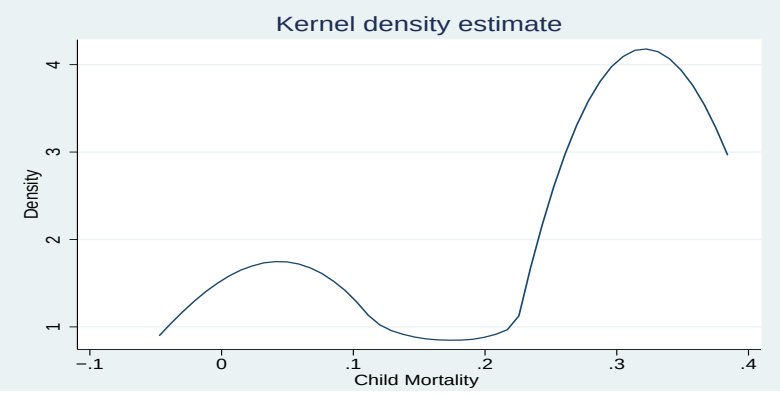
(a) Child Mortality $(1 - \pi)$ (1950)



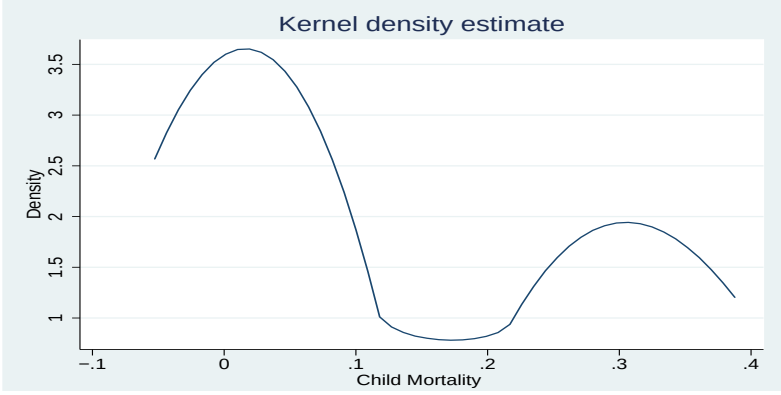
(b) Child Mortality $(1 - \pi)$ (2050)

Cross-Sectional Implications:

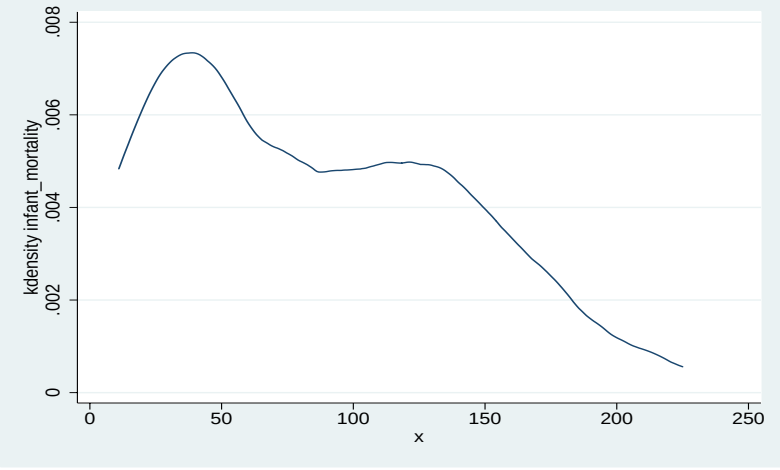
Child Mortality (81 countries, $\underline{T} \in [46, 50]$)



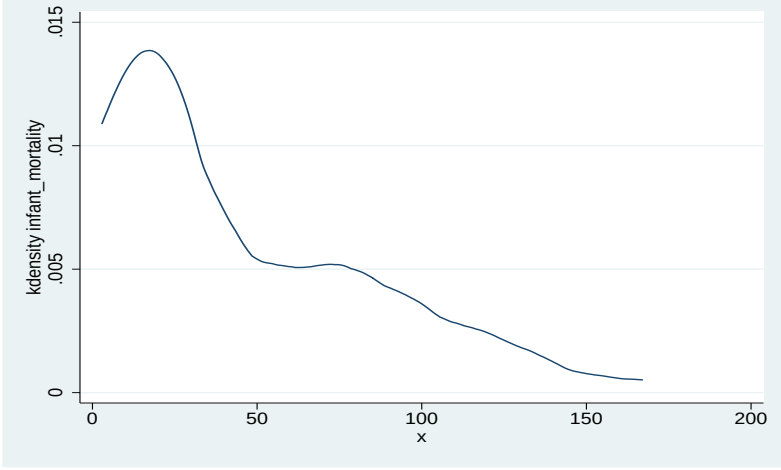
(a) Child Mortality $(1 - \pi)$ (1950)



(b) Child Mortality $(1 - \pi)$ (2050)



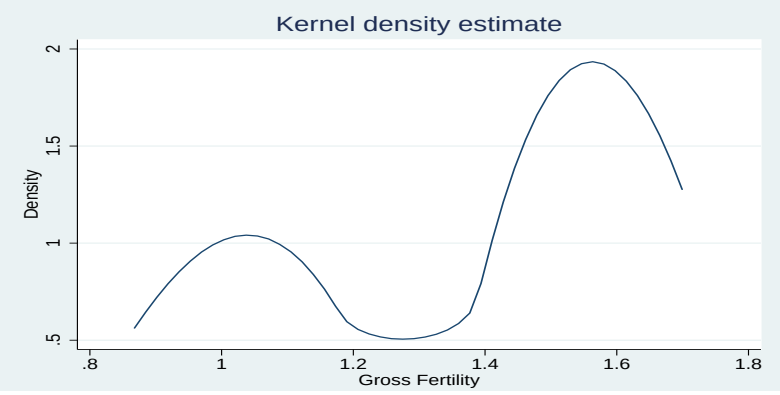
(c) Infant Mortality 1970



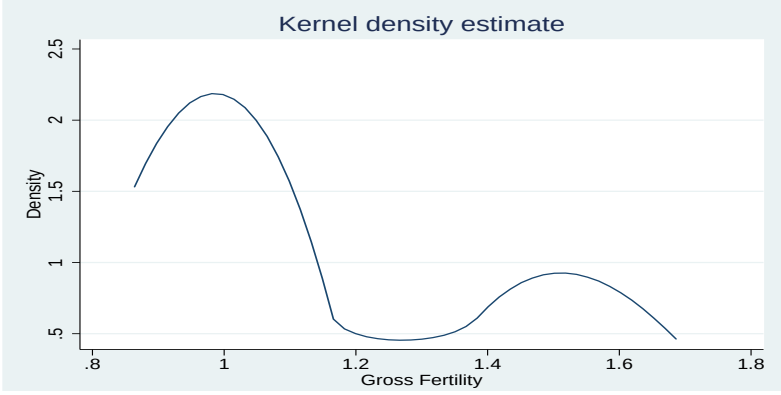
(d) Infant Mortality 2000

Cross-Sectional Implications:

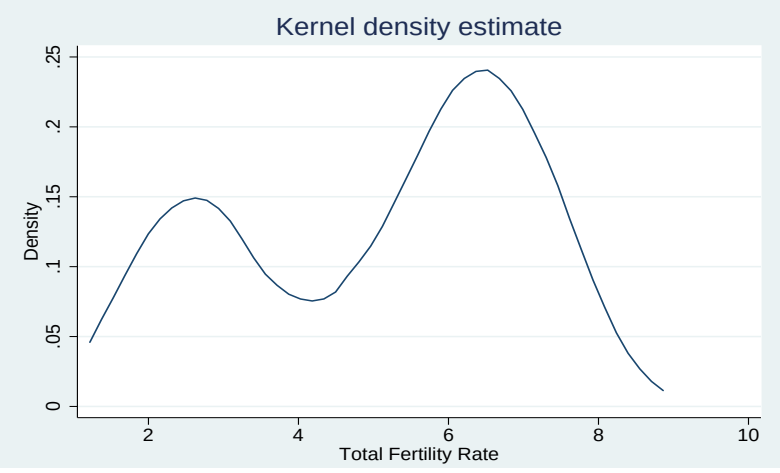
Gross Fertility (81 countries, $\underline{T} \in [46, 50]$)



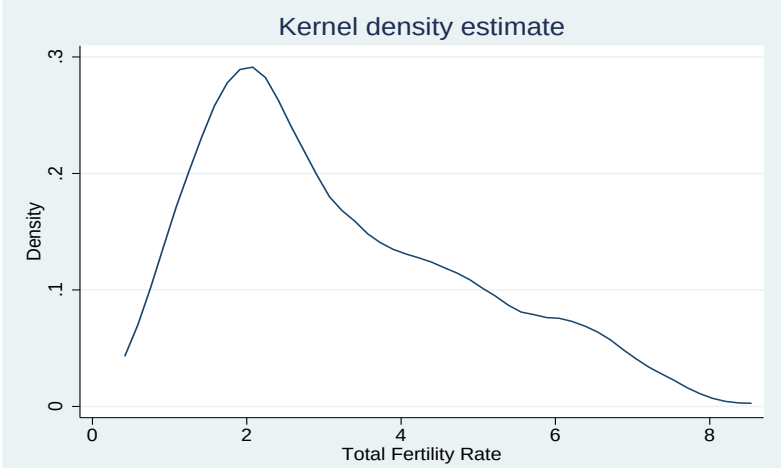
(a) Gross Fertility (1950)



(b) Gross Fertility (2050)



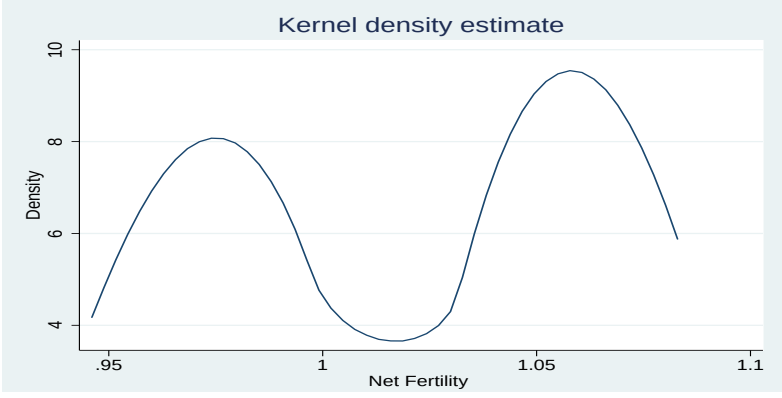
(c) Total Fertility Rate 1970



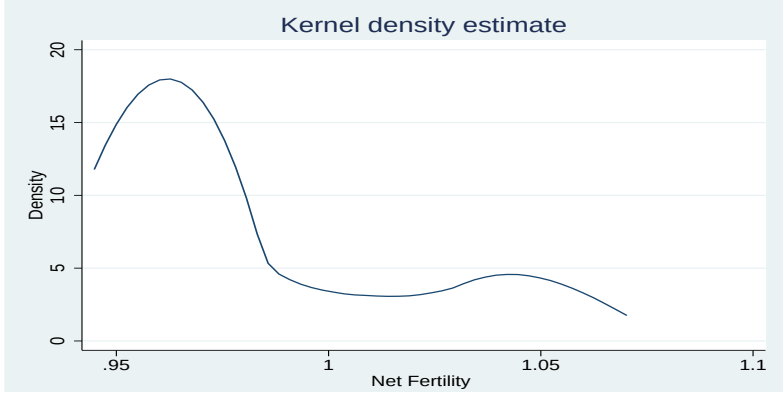
(d) Total Fertility Rate 2000

Cross-Sectional Implications:

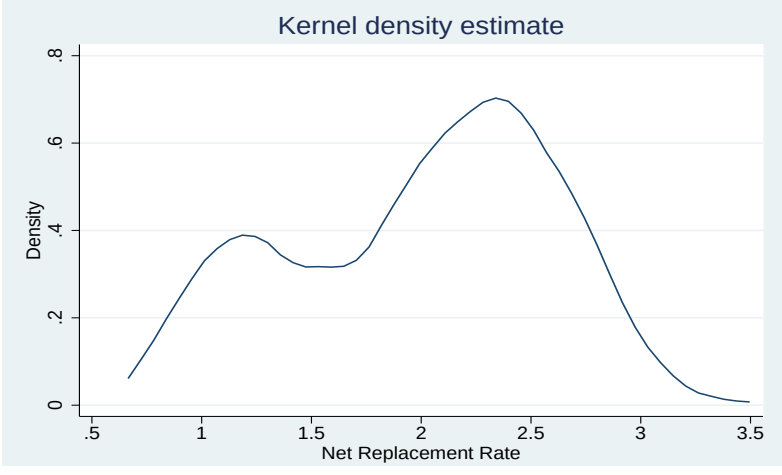
Net Fertility (81 countries, $\underline{T} \in [46, 50]$)



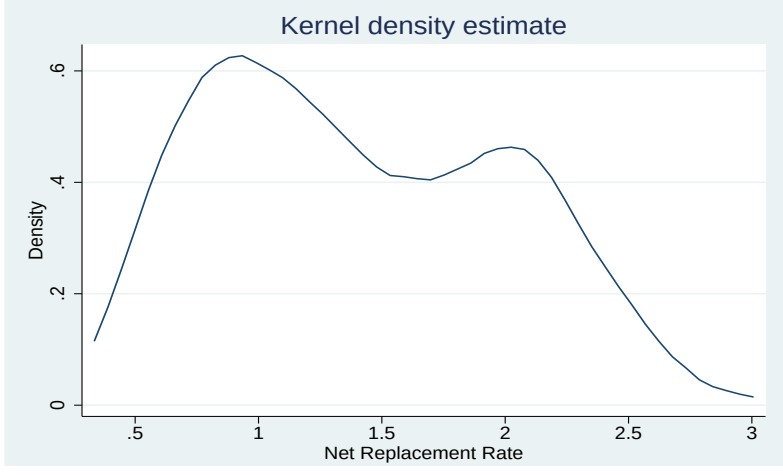
(a) Net Fertility (1950)



(b) Net Fertility (2050)



(c) Net Replacement Rate 1970



(d) Net Replacement Rate 2000

Simulation and Data

Timing of transition

- Child Mortality improvements are more rapid than in simulation;
- Exit from trap is "quicker in the data" compared to the simulation (acceleration of development);

Simulation and Data

Timing of transition

- Child Mortality improvements are more rapid than in simulation;
- Exit from trap is "quicker in the data" compared to the simulation (acceleration of development);
- Controlled experiment: Only variation in $\underline{T}$ leading to a constant speed of exit from trap;
  - Cross-country spillovers in medical knowledge and technology
  - Public policies
  - Institutional change

Summary

- Unified theory of the economic and demographic transition in line with historical and cross-country patterns of development that accounts for changes in education composition and differential fertility;
- Endogenous transition (exit from development trap)
  - requires *joint* improvements in T, π, A
  - highlights different roles of adult longevity (composition) and child mortality (fertility):
  - Take-off: *iff* change in λ
- Predictions on both time series and cross country dimension
- Study the distinct role of mortality: shocks and extrinsic differences.