Unified Growth Theory and Comparative Development

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Economic Growth and Comparative Development
Fundamental Research Questions

- What is the origin of the vast inequality in income per capita across countries and regions?
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- What are the factors that inhibited the convergence of poor economies toward richer ones in the past decades?
- What is the role of deep-rooted factors in explaining the observed patterns of comparative development?
Limitations of Non-Unified Growth Theory

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  - Factors that hindered convergence across countries
  - Importance of deep-rooted factors in comparative development
Unified Growth Theory

- Captures the:

  - Process of development in its entirety
  - Forces that permitted DCs to transition from the Malthusian Epoch to sustained growth
  - Hurdles faced by LDCs in their transitions from stagnation to growth
  - Persistent effect of initial biogeographical factors on the growth process

- Encompasses:
  - Existing hypotheses about the role of geographical, cultural, institutional and genetic factors in comparative development
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The Fundamental Challenge

- A unified theory of economic growth that accounts for the:
  
  - Epoch of Malthusian stagnation
  - Take-off from the Malthusian Regime
  - Emergence of human capital as a significant factor in the growth process
  - Demographic transition
  - Shift to sustained economic growth
  - Emergence of inequality in income per capita across countries
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Origins of the Phase Transition

- Design of a dynamical system that permits a phase transition:
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  - Escape from a stable Malthusian equilibrium:
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- Vanishing Malthusian equilibrium
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- Evolution of a latent state variable – the demand for human capital
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  - Ultimately changes the dynamical system qualitatively:
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  - Ultimately changes the dynamical system qualitatively:
    - The Malthusian equilibrium vanishes endogenously
    - The economy gravitates towards the emerging Modern Growth Regime
Characteristics of the Main Transitions

- Transition from Malthusian to Post-Malthusian Regime:
  - Faster rate of technological progress
  - Faster rate of population growth
  - Insignificant investment in human capital
  - Onset of growth in income per capita

- Transition from the Post-Malthusian to Modern Growth Regime:
  - Faster rate of technological progress
  - Faster rate of human capital accumulation
  - Decline in population growth
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The underlying forces that govern these transitions:
Suggestive Evidence

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    - population size and quality
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  - The effect of changes in the size and the quality of the population on:
Suggestive Evidence

- The underlying forces that govern these transitions:
  - The effect of changes in the technological environment on:
    - population size and quality
  - The effect of changes in the size and the quality of the population on:
    - the rate of technological progress
The Basic Structure of the Model

- Overlapping-generations economy
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- $t = 0, 1, 2, 3...$
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- $t = 0, 1, 2, 3...$
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- 2 factors of production:
  - Labor (measured in efficiency units)
The Basic Structure of the Model

- Overlapping-generations economy
- \( t = 0, 1, 2, 3 \ldots \)
- One homogeneous good
- 2 factors of production:
  - Labor (measured in efficiency units)
  - Land
Factor Supply

- Land is fixed over time
Factor Supply

- Land is fixed over time
  - Surface of planet earth
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  - Surface of planet earth
- Efficiency units of labor evolves endogenously
Factor Supply

• Land is fixed over time
  • Surface of planet earth

• Efficiency units of labor evolves endogenously
  • Determined by households’ decisions about the number and level of human capital of their children
Main Elements

- The Malthusian Structure
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- Sources of Technological Progress
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- Origins of Human Capital Formation
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- Triggers of the Demographic Transition
The Malthusian Structure

- A subsistence consumption constraint
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- Positive effect of income on population
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  - \( y \uparrow \rightarrow L \uparrow \)
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- Positive effect of income on population
  - \( y \uparrow \implies L \uparrow \)
- Fixed factor of production – Land
The Malthusian Structure

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- Positive effect of income on population
  - $y \uparrow \implies L \uparrow$
- Fixed factor of production – Land
  - $L \uparrow \implies AP_L \downarrow \implies y \downarrow$
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  - \( y \uparrow \implies L \uparrow \)

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- Output per capita fluctuates (with a negligible trend) around a constant level in the long-run
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  - \( y \uparrow \implies L \uparrow \)

- Fixed factor of production – Land
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- Output per capita fluctuates (with a negligible trend) around a constant level in the long-run
  - Reflecting diminishing returns to labor & positive effect of income on population
Production

- The output produced in period $t$

$$Y_t = H_t^\alpha (A_t X)^{1-\alpha}$$

- $H_t \equiv$ efficiency units of labor
- $A_t \equiv$ technological level
- $X \equiv$ land
Production

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$$Y_t = H_t^\alpha (A_t X)^{1-\alpha}$$

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- Output per worker produced at time $t$

$$y_t = h_t^\alpha x_t^{1-\alpha}$$

- $h_t \equiv H_t/L_t \equiv$ efficiency units per-worker
- $x_t \equiv (A_t X)/L_t \equiv$ effective resources per worker
The Malthusian Structure – Effects of Technological Progress

- Very short-run (for a given population):
  - $A_t \uparrow \implies y_t \uparrow$ (above $\bar{y}$)
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- Short-run (initial adjustment of population):
  - $y_t \uparrow \implies L_t \uparrow$

- Long-run (population reaches a new steady-state):
  - $L_t \uparrow \implies y \downarrow$ (back to $\bar{y}$)
Sources of Technological Progress

- Earlier stages of development
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- Earlier stages of development
  - Population size positively affects technological progress:
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- Channels:
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- Channels:
  - Supply of innovations
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- Channels:
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  - Demand for innovations
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  - Division of labor
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- Earlier stages of development
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- Channels:
  - Supply of innovations
  - Demand for innovations
  - Diffusion of knowledge
  - Division of labor
  - Extent of trade
Sources of Technological Progress

- Later Stages of Development

Human capital positively affects technological progress:

\[ \text{Educated individuals have an advantage in adopting and advancing new technologies} \]
Sources of Technological Progress

- Later Stages of Development
  - Human capital positively affects technological progress
    
    \[ e_t \uparrow \implies A_t \uparrow \]
Sources of Technological Progress

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    \[ e_t \uparrow \quad \implies \quad A_t \uparrow \]

  - Educated individuals have an advantage in adopting and advancing new technologies
Technological Progress

\[ g_{t+1} \equiv \frac{A_{t+1} - A_t}{A_t} = g(e_t, L_t) \]

- \( g_{t+1} \equiv \) rate of tech progress
- \( e_t \equiv \) education
- \( L_t \equiv \) population size
Technological Progress

\[ g_{t+1} = g(e_t, L_t) \]
Technological Progress

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- \( g_e(e_t, L_t) > 0 \) and \( g_{ee}(e_t, L_t) < 0 \)
  - Education has a positive and diminishing effect on technological progress
Technological Progress

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- \( g_e(e_t, L_t) > 0 \) and \( g_{ee}(e_t, L_t) < 0 \)
  - Education has a positive and diminishing effect on technological progress
- \( g_L(e_t, L_t) > 0 \) and \( g_{LL}(e_t, L_t) < 0 \)
  - The scale of the economy has a positive and diminishing effect on technological progress
Technological Progress

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- \( g_e(e_t, L_t) > 0 \) and \( g_{ee}(e_t, L_t) < 0 \)
  - Education has a positive and diminishing effect on technological progress

- \( g_L(e_t, L_t) > 0 \) and \( g_{LL}(e_t, L_t) < 0 \)
  - The scale of the economy has a positive and diminishing effect on technological progress

- \( g(0, L) > 0 \) for \( L > 0 \)
  - Technological progress is positive at the outset
Technological Progress

\[ g_{t+1} \]

\[ e_t \]
Technological Progress

\[ g_{t+1} = g(e_t, L^L) \]

\[ g(0, L^L) \]

\[ e_t \]
The Effect of Population Size on Technological Progress

\[ g_{t+1} = g(e_t, L^H) \]

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\[ g(0, L^H) \]

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Origins of Human Capital Formation

- The increase in the rate of technological progress increases the demand for human capital
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- Human capital permits individuals to better cope with the changes in the technological environment.
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- The increase in the rate of technological progress increases the demand for human capital
  - Human capital permits individuals to better cope with the changes in the technological environment
  - The introduction of new technologies is skill-biased in the short-run, although the nature of the technology can be skill-biased or skill-saving in the long run
Human Capital Formation
Human Capital Formation

Human capital of an individual who joins the labor force in period \( t + 1 \)

\[
h_{t+1} = h(e_{t+1}, g_{t+1})
\]
Human Capital Formation

Human capital of an individual who joins the labor force in period $t + 1$

$$h_{t+1} = h(e_{t+1}, g_{t+1})$$

- $e_{t+1} \equiv$ the individual education level (determined by parental investment, subject to their subsistence constraint, in period $t$)
- $g_{t+1} \equiv$ rate of tech progress
Human Capital Formation

\[ h_{t+1} = h(e_{t+1}, g_{t+1}) \]

- \( h_e(e, g) > 0 \) and \( h_{ee}(e, g) < 0 \)
  - HC is increasing (at decreasing rates) in the parental time investment in the education of the child
Human Capital Formation

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- \( h_e(e, g) > 0 \) and \( h_{ee}(e, g) < 0 \)
  - HC is increasing (at decreasing rates) in the parental time investment in the education of the child
- \( h_g(e, g) < 0 \) and \( h_{gg}(e, g) > 0 \)
  - Obsolescence of HC in a changing technological environment
Human Capital Formation

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- \( h_e(e, g) > 0 \) and \( h_{ee}(e, g) < 0 \)
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  - Obsolescence of HC in a changing technological environment

- \( h_{eg}(e, g) > 0 \)
  - Education lessens the obsolescence of HC in a changing technological environment
Human Capital Formation

\[ h_{t+1} = h(e_{t+1}, g_{t+1}) \]

- \( h_e(e, g) > 0 \) and \( h_{ee}(e, g) < 0 \)
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- \( h_{eg}(e, g) > 0 \)
  - Education lessens the obsolescence of HC in a changing technological environment

- \( h(0, g) > 0 \)
  - Basic level of human capital
Human Capital Formation

$h_{t+1}$

\[ h_{t+1} = h(t+1, 0) \]
Human Capital Formation

\[ h_{t+1} = h(e_{t+1}, 0) \]

\[ h(0, 0) = 1 \]
Effect of Technological Progress on Human Capital Formation

\[ h_{t+1} = h(e_{t+1}, 0) \]

\[ h_{t+1} = h(e_{t+1}, g) \]

\( h(0, 0) = 1 \)

\( h(0, g) \)
Triggers of the Demographic Transition

- The rise in the demand for human capital induces parents to substitute quality for quantity of children.
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The rise in income along with the rise in the potential return to human capital generates:
Triggers of the Demographic Transition

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- The rise in income along with the rise in the potential return to human capital generates:
  - An income effect – more income to spend on children.
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    - The opportunity cost of raising children increases
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  - Substitution effects
    - The opportunity cost of raising children increases
    - Return to investment in child quality increases
Triggers of the Demographic Transition

- Early part of the second phase of industrialization:
Triggers of the Demographic Transition

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  - The income effect dominates (moderate demand for human capital): 

...
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- Early part of the second phase of industrialization:
  - The income effect dominates (moderate demand for human capital):
    - Population growth & human capital formation increase:
Triggers of the Demographic Transition

- Early part of the second phase of industrialization:
  - The income effect dominates (moderate demand for human capital):
    - Population growth & human capital formation increase:

- Later part of the second phase of industrialization:
Triggers of the Demographic Transition

- Early part of the second phase of industrialization:
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    - Population growth & human capital formation increase:

- Later part of the second phase of industrialization:
  - The substitution effect dominates (significant demand for human capital):
Triggers of the Demographic Transition

- Early part of the second phase of industrialization:
  - The income effect dominates (moderate demand for human capital):
    - Population growth & human capital formation increase:

- Later part of the second phase of industrialization:
  - The substitution effect dominates (significant demand for human capital):
    - Population growth declines & human capital formation increases further
Individuals

- Live for 2 periods

\[ \tau \equiv \text{time required to raise a child, regardless of quality} \]
\[ \tau + e_{t+1} \equiv \text{time to raise a child with education} \]
Individuals

- Live for 2 periods
- Childhood (1st Period):
Individuals

- Live for 2 periods

- Childhood (1st Period):
  - Consume a fraction of parental time endowment
Individuals

- Live for 2 periods

- Childhood (1st Period):
  - Consume a fraction of parental time endowment
  - The required time increases with child quality
Individuals

- Live for 2 periods

- Childhood (1st Period):
  - Consume a fraction of parental time endowment
  - The required time increases with child quality
    - $\tau \equiv$ time required to raise a child, regardless of quality
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    - \( \tau + e_{t+1} \equiv \) time to raise a child with education \( e_{t+1} \)
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- Parenthood (2nd Period):
Individuals

- Live for 2 periods

- Childhood (1st Period):
  - Consume a fraction of parental time endowment
  - The required time increases with child quality
    - \( \tau \equiv \) time required to raise a child, regardless of quality
    - \( \tau + e_{t+1} \equiv \) time to raise a child with education \( e_{t+1} \)

- Parenthood (2nd Period):
  - Allocate the time endowment between childrearing and work
Live for 2 periods

Childhood (1st Period):
- Consume a fraction of parental time endowment
- The required time increases with child quality
  \[
  \tau \equiv \text{time required to raise a child, regardless of quality}
  \]
  \[
  \tau + e_{t+1} \equiv \text{time to raise a child with education } e_{t+1}
  \]

Parenthood (2nd Period):
- Allocate the time endowment between childrearing and work
- Choose the optimal mixture of child quantity and quality
Individuals

- Live for 2 periods

- Childhood (1st Period):
  - Consume a fraction of parental time endowment
  - The required time increases with child quality
    - $\tau \equiv$ time required to raise a child, regardless of quality
    - $\tau + e_{t+1} \equiv$ time to raise a child with education $e_{t+1}$

- Parenthood (2nd Period):
  - Allocate the time endowment between childrearing and work
  - Choose the optimal mixture of child quantity and quality
  - Consume
Preferences

- The utility function of individual $t$ (adult at time $t$)

$$u^t = (1 - \gamma) \ln(c_t) + \gamma \ln(n_t h_{t+1})$$

- $c_t \equiv$ consumption of individual $t$
- $n_t \equiv$ number of children of individual $t$
- $h_{t+1} \equiv$ level of human capital of each child
Budget and Subsistence Consumption Constraints

\[ z_t n_t (\tau + e_{t+1}) + c_t \leq z_t \]

- \( z_t \equiv \) potential income of individual \( t \)
- \( \tau \equiv \) time required to raise a child, regardless of quality
- \( \tau + e_{t+1} \equiv \) time needed to raise a child with education \( e_{t+1} \)
Budget and Subsistence Consumption Constraints

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- \( \tau \equiv \) time required to raise a child, regardless of quality
- \( \tau + e_{t+1} \equiv \) time needed to raise a child with education \( e_{t+1} \)

\[ z_t \equiv y_t = h_t^\alpha x_t^{1-\alpha} = z(e_t, g_t, x_t) \]

- Subsistence consumption constraint:
  \[ c_t \geq \tilde{c} \]
Consist of: Modeling and Optimization

\[ n_t(\tau + e_{t+1}) \]

\[ z^0 \rightarrow C_t \]

Subsistence Consumption
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

\[ z^0 \]

\[ \gamma \]

\[ 1 \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

\[ c_t \]

\[ \tilde{c} \]

\[ \gamma \]

\[ z^0 \]

\[ 1 \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

\[ z^0 \]

\[ \gamma \]

\[ C_t \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ \tilde{c}, z^0 \]

\[ \gamma \]

\[ 1 \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ c \]

\[ \tilde{z} \]

\[ z^0 \]

\[ z^1 \]

\[ 1 \]

\[ \gamma \]

\[ C_t \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ \tilde{c} \]

\[ z^0 \]

\[ z^1 \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

\[ \tilde{z} \]

\[ z^0, z^1, z^2 = \tilde{z} \]

Subsistence Consumption
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ 1 \]

\[ \gamma \]

\[ \tilde{C} \quad Z^0 \quad Z^1 \quad Z^2 = \tilde{Z} \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ \gamma \]

\[ C, Z^0, Z^1, Z^2 = \tilde{Z}, Z^3 \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ c_t \]

Income Expansion Path
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ \tilde{z} \]

\[ \tilde{\gamma} \]

\[ z^0, z^1, z^2 = \tilde{z}, z^3, z^4 \]
**Constraint and Optimization**

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ z^0 \quad z^1 \quad z^2 = \tilde{z} \quad z^3 \quad z^4 \]
Constraint and Optimization

\[ n_t(\tau + e_{t+1}) \]

Subsistence Consumption

\[ z^0, z^1, z^2 = \tilde{z}, z^3, z^4 \]

Income Expansion Path
Optimal Investment in Child Quality

\[ e_{t+1} \]

\[ g_{t+1} \]
Optimal Investment in Child Quality

\[ e_{t+1} = e(g_{t+1}) \]
Optimization: Quantity and Quality of Children

- Time devoted to children:

\[ n_t(\tau + e_{t+1}) = \begin{cases} 
\gamma & \text{if } z_t \geq \tilde{z} \\
1 - \frac{c}{z_t} & \text{if } z_t \leq \tilde{z}
\end{cases} \]

\[ n_t(\tau + e_{t+1}) = \begin{cases} 
\gamma & \text{if } z_t \geq \tilde{z} \\
1 - \frac{c}{z_t} & \text{if } z_t \leq \tilde{z}
\end{cases} \]
Optimization: Quantity and Quality of Children

- Time devoted to children:

\[
n_t(\tau + e_{t+1}) = \begin{cases} 
\gamma & \text{if } z_t \geq \tilde{z} \\
1 - \frac{\tilde{c}}{z_t} & \text{if } z_t \leq \tilde{z}
\end{cases}
\]

- \( z_t = \tilde{z} \equiv \frac{\tilde{c}}{1 - \gamma} \) is the highest level of potential income such that the subsistence constraint is still binding.
**Optimization: Quantity and Quality of Children**

- Time devoted to children:

\[
\begin{align*}
n_t(\tau + e_{t+1}) &= \begin{cases} 
\gamma & \text{if } z_t \geq \tilde{z} \\
1 - \frac{\tilde{c}}{z_t} & \text{if } z_t \leq \tilde{z}
\end{cases}
\end{align*}
\]

- \( z_t = \tilde{z} \equiv \frac{\tilde{c}}{(1 - \gamma)} \) is the highest level of potential income such that the subsistence constraint is still binding.

\[
e_{t+1} = e(g_{t+1}) \implies \]

\[
\begin{align*}
n_t &= \begin{cases} 
\frac{\gamma}{\tau + e(g_{t+1})} & \equiv n^b(g_{t+1}) & \text{if } z_t \geq \tilde{z} \\
\frac{1 - [\tilde{c}/z_t]}{\tau + e(g_{t+1})} & \equiv n^a(g_{t+1}, z(e_t, g_t, x_t)) & \text{if } z_t \leq \tilde{z}
\end{cases}
\end{align*}
\]
Malthusian Epoch

\[ nT \]

\[ C \]
Malthusian Epoch

\[ n \tau \]

\[ \tilde{c} \]

\[ \gamma \]

Subsistence Consumption
Malthusian Epoch

Subsistence Consumption

\[ \gamma \]

\[ \tau \]
Malthusian Epoch

\[ \tau \]

Subsistence Consumption

\[ \tilde{C} \]
Malthusian Epoch

\[ \ln T \]

Subsistence Consumption

\[ \tilde{C} \]
Malthusian Epoch

Subsistence Consumption

\[ \tilde{C} \]

\[ nT \]

\[ \gamma \]

\[ \tau \]
Malthusian Epoch

Subsistence Consumption

\[ \gamma \]

\[ \tau \]

\[ \tilde{c} \]

\[ \checkmark \]

\[ n \tau \]

\[ C \]
Malthusian Epoch

\[ \eta \tau \]

Subsistence Consumption

\[ \gamma \]

\[ \tau \]

\[ \hat{C} \]

\[ C \]
Malthusian Epoch

\[ \eta \tau \]

Subsistence Consumption

\[ \gamma \]

\[ \tau \]

\[ \hat{c} \]

\[ C \]
Malthusian Epoch

\[ n \tau \]

Subsistence Consumption

\[ C \]
Post-Demographic Transition

\[ nT \]

Subsistence Consumption

\[ \hat{c} \]

\[ \hat{z} \]
Post-Demographic Transition

Subsistence Consumption

\[ \eta \tau \]

\[ \hat{c} \]

\[ \tilde{z} \]
Population Dynamics

\[ L_{t+1} = n_t L_t \]

\[ L_{t+1} = \begin{cases} 
  n^b(g_{t+1})L_t & \text{if } z_t \geq \tilde{z} \\
  n^a(g_{t+1}, z(e_t, g_t, x_t))L_t & \text{if } z_t \leq \tilde{z} 
\end{cases} \]
Dynamics of the Level of Resources per Worker

\[ x_{t+1} = \frac{A_{t+1}X}{L_{t+1}} = \frac{(1 + g_{t+1})A_tX}{n_t L_t} = \frac{1 + g_{t+1}}{n_t} x_t \]

\[ x_{t+1} = \begin{cases} 
\frac{[1+g(e_t,L_t)][\tau^q + \tau^e e(g(e_t,L_t))]}{\gamma} x_t \equiv \phi^b(e_t; L_t)x_t & z_t \geq \tilde{z} \\
\frac{[1+g(e_t,L_t)][\tau + e(g(e_t,L_t))]}{1 - [\bar{c}/z(e_t,g_t,x_t)]} x_t \equiv \phi^a(e_t, g_t, x_t, L_t)x_t & z_t \leq \tilde{z},
\end{cases} \]
A sequence \( \{x_t, e_t, g_t, L_t\}_{t=0}^{\infty} \) such that:

\[
\begin{align*}
  x_{t+1} &= \phi(e_t, g_t, x_t, L_t)x_t \\
  e_{t+1} &= e(g(e_t, L_t)) \\
  g_{t+1} &= g(e_t, L_t) \\
  L_{t+1} &= n(e_t, g_t, x_t, L_t)L_t
\end{align*}
\]
A sequence \( \{g_t, e_t; L\}_{t=0}^{\infty} \) such that:

\[
\begin{align*}
g_{t+1} &= g(e_t; L) \\
e_{t+1} &= e(g_{t+1})
\end{align*}
\]
The Effect of Education on Technology

\[ g_{t+1} = g(e_t, L^L) \]
The Effect of Technology on Education

\[ e_{t+1} = e(g_{t+1}) \]
The Effect of Technology on Education: Flipped Axis

\[ e_{t+1} = e(g_{t+1}) \]
The Evolution of Education and Technology: For a Given Population Size

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^L) \]

\[ g(0, L^L) \]
The Evolution of Education and Technology: For a Given Population Size

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^L) \]
The Evolution of Education and Technology: For a Given Population Size

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^L) \]

\[ g_t = g(0, L^L) \]
The Evolution of Education and Technology: For a Given Population Size

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^L) \]
The Evolution of Education and Technology: For a Given Population Size

\[ \hat{e}_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^L) \]
The Evolution of Education and Technology: For a Given Population Size

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^L) \]
The Evolution of Education and Technology: For a Given Population Size

\[ g_{t+1} = g(e_t, L^L) \]

\[ e_{t+1} = e(g_{t+1}) \]
The Evolution of Education and Technology: For a Given Population Size

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^L) \]
The Evolution of Education and Technology

\[ e_{t+1} = e(g_{t+1}) \]
\[ g_{t+1} = g(e_t, L^0) \]
The Evolution of Education and Technology

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^1) \]
The Evolution of Education and Technology

\[ e_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^2) \]
The Evolution of Education and Technology

\[ g_{t+1} = e(g_{t+1}) \]

\[ g_{t+1} = g(e_t, L^3) \]
The Evolution of Education and Technology

\[
\begin{align*}
g_{t+1} &= e(g_{t+1}) \\
g_{t+1} &= g(e_t, L^M)
\end{align*}
\]
The Evolution of Education and Technology

\[ g_{t+1} = g(e_t, L^5) \]

\[ e_{t+1} = e(g_{t+1}) \]
The Evolution of Education and Technology

\[ g^{t+1} = g(t, L^H) \]

\[ e^{t+1} = e(g^{t+1}) \]

\[ g(0, L^H) \]

\[ g^H(L^H) \]

\[ e^H(L^H) \]
The Evolution of Education and Technology

\[ g_{t+1} = g(e_t, L^H) \]

\[ e_{t+1} = e(g_{t+1}) \]

- \( g^H(L^H) \)
- \( g(0, L^H) \)
- \( g \)
The Evolution of Education and Resources Per Worker: Small Population

Conditional Malthusian Frontier:

\[ x_{t+1} = x_t + e(L) x_t \]

\[ e_t = \text{education and resources per worker} \]
The Evolution of Education and Resources Per Worker: Small Population

\[ x_t = \tilde{z} e^L(\tilde{L}) \]

Conditional Malthusian Frontier

\[ z_t = \tilde{z} \]
The Evolution of Education and Resources Per Worker: Small Population

\[ x_{t+1} = x_t \]

Conditional Malthusian Frontier

\[ z_t = \tilde{z} \]
The Evolution of Education and Resources Per Worker: Small Population

Conditioned Malthusian Frontier

\[ x_{t+1} = x_t \]

\[ z_t = \tilde{z} \]
The Evolution of Education and Resources Per Worker: Small Population

The Dynamical System

Conditional Malthusian Frontier:

\[ z_t = \tilde{z} \]

\[ x_{t+1} = x_t \]

\[ X_t \]

\[ e^L(L) \]

\[ \dot{e}(L) \]

\[ \dot{x}^L(L) \]

\[ e_t \]
The Evolution of Education and Resources Per Worker: Small Population

\[ x_{t+1} = x_t \]

\[ e^L(L) \]

\[ e^L(L) \]

Conditional Malthusian Frontier

\[ z_t = \bar{z} \]
The Evolution of Education and Resources Per Worker: Small Population

\[ x_{t+1} = x_t \]

\[ x^L(L) \]

\[ e^L(L) \]

\[ \dot{e}(L) \]

\[ \hat{e}(L) \]

Conditional Malthusian Frontier

\[ z_t = \bar{z} \]
The Evolution of Education and Resources Per Worker: Intermediate Population

\[ x_{t+1} = x_t \]

\[ \hat{e}(L) \]

Conditional Malthusian Frontier

\[ z_t = \bar{z} \]
The Evolution of Education and Resources Per Worker: Intermediate Population

\[ x_{t+1} = x_t \]

\[ e(L) \]

Conditional Malthusian Frontier

\[ z_t = \bar{z} \]
The Evolution of Education and Resources Per Worker: Intermediate Population

\[ x_{t+1} = x_t \]

\[
X_t \\
\hat{e}(L) \\
\hat{e}(L) \\
\end{array}
\]

Conditional Malthusian Frontier

\[ z_t = \bar{z} \]
The Evolution of Education and Resources Per Worker: Intermediate Population

\[ x_{t+1} = x_t \]

\[ x^L(L) \quad e^L(L) \quad e^u(L) \quad \hat{e}(L) \quad e^H(L) \]

Conditional Malthusian Frontier

\[ z_t = \bar{z} \]
The Evolution of Education and Resources Per Worker: Intermediate Population

\[
x_{t+1} = x_t + \hat{e}(L)
\]

\[
x^L(L) \rightarrow e^L(L) \rightarrow e^u(L) \rightarrow \hat{e}(L) \rightarrow e^H(L) \rightarrow \bar{z} \rightarrow \text{Conditional Malthusian Frontier}
\]
The Evolution of Education and Resources Per Worker: Large Population

\[ x_{t+1} = x_t \]

Conditional Malthusian Frontier

\[ z_t = \hat{z} \]
The Evolution of Education and Resources Per Worker: Large Population

\[ x_{t+1} = x_t \]

\[ \hat{e}(L) \]

\[ e^H(L) \]

Conditional Malthusian Frontier

\[ z_t = \tilde{z} \]
The Evolution of Education and Resources Per Worker: Large Population

\[ x_{t+1} = x_t \]

\[ x_t \]

\[ e(L) \]

\[ e^H(L) \]

Conditional Malthusian Frontier

\[ z_t = \bar{z} \]
The Evolution of Education and Resources Per Worker: Large Population

\[ x_{t+1} = x_t \]

- \( x_t \) represents the education and resources per worker at time \( t \).
- The diagram illustrates the evolution of education and resources over time, with the conditional Malthusian frontier indicated by the dotted line.
- The dashed line \( \hat{e}(L) \) and \( e^H(L) \) represent specific curves or levels of education and resources.
- The graph shows the interplay between education and resources, with arrows indicating the direction of change.
Simulation

Growth rates and education, 5-period moving average

Source: Lagerlöf (RED 2006)
Implications

- The Malthusian interaction between technology & population
Implications

- The Malthusian interaction between technology & population
  - Acceleration in technological progress
Implications

- The Malthusian interaction between technology & population
  - Acceleration in technological progress
    - \(\implies\) Industrial demand for human capital

\[\text{Human capital formation} \implies \text{Decline in fertility rates} \implies \text{Further technological progress}\]

\[\text{Decline in population growth} \implies \text{Economic growth is freed from counterbalancing effects of population}\]

\[\text{Technological progress, human capital & decline in population growth} \implies \text{Sustained economic growth}\]
The Malthusian interaction between technology & population

- Acceleration in technological progress
  - $\Rightarrow$ Industrial demand for human capital
- Human capital formation
  - $\Rightarrow$ Decline in fertility rates
  - $\Rightarrow$ Further technological progress

Decline in population growth $\Rightarrow$ Economic growth is freed from counterbalancing effects of population technological progress, human capital & decline in population growth $\Rightarrow$ Sustained economic growth
The Malthusian interaction between technology & population

- Acceleration in technological progress
  - Industrial demand for human capital

- Human capital formation
  - Decline in fertility rates
  - Further technological progress

- Decline in population growth
  - Economic growth is freed from counterbalancing effects of population
Implications

- The Malthusian interaction between technology & population
  - Acceleration in technological progress
    - ➞ Industrial demand for human capital
  - Human capital formation
    - ➞ Decline in fertility rates
    - ➞ Further technological progress
  - Decline in population growth
    - ➞ Economic growth is freed from counterbalancing effects of population
  - Technological progress, human capital & decline in population growth
    - ➞ Sustained economic growth
Variations in the timing of the take-off contributed significantly to the divergence in income per capita in the past two centuries.
Implications for Comparative Development

- Variations in the timing of the take-off contributed significantly to the divergence in income per capita in the past two centuries.
- Differences in the economic performance across countries reflect:
  - Variations in country-specific characteristics that affect
Implications for Comparative Development

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- Differences in the economic performance across countries reflect:
  - Variations in country-specific characteristics that affect:
    - The pace of technological progress.
Implications for Comparative Development

- Variations in the timing of the take-off contributed significantly to the divergence in income per capita in the past two centuries.

- Differences in the economic performance across countries reflect:
  
  - Variations in country-specific characteristics that affect:
    
    - The pace of technological progress
    - The intensity of human capital formation
Variations in Country-Specific Characteristics Conducive for Technological Progress

\[ g_{t+1}^i = g(e_t^i, L_t^i, \Omega_t^i) \]

\[ \Omega_t^i \equiv \text{characteristics affecting tech progress in country } i: \]
Variations in Country-Specific Characteristics Conducive for Technological Progress

\[ g_{t+1}^i = g(e_t^i, L_t^i, \Omega_t^i) \]

\( \Omega_t^i \equiv \text{characteristics affecting tech progress in country } i: \)

- Protection of intellectual property rights (policy)
Variations in Country-Specific Characteristics Conducive for Technological Progress

$$g^i_{t+1} = g(e^i_t, L^i_t, \Omega^i_t)$$

$$\Omega^i_t \equiv \text{characteristics affecting tech progress in country } i:\n$$

- Protection of intellectual property rights (policy)
- The stock of knowledge within a society
Variations in Country-Specific Characteristics Conducive for Technological Progress

\[ g_{t+1}^i = g(e_t^i, L_t^i, \Omega_t^i) \]

\[ \Omega_t^i \equiv \text{characteristics affecting tech progress in country } i: \]

- Protection of intellectual property rights (policy)
- The stock of knowledge within a society
- The propensity of a country to trade (geography & policy)
  - Technological diffusion
  - Specialization and technological progress via learning by doing
  - Innovative Culture & Institutions
Variations in Country-Specific Characteristics Conducive for Technological Progress

- Cultural and religious composition of society
  - Attitude toward knowledge creation and diffusion (e.g., The Inquisition)
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  - Incentives to block or promote technological innovation (e.g., Luddites; landowners)
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  - Wider spectrum of traits are more likely to contain the ones complementary to the adoption or implementation of new technologies
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- Cultural and religious composition of society
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- Cultural and population diversity
  - Wider spectrum of traits are more likely to contain the ones complementary to the adoption or implementation of new technologies

- Abundance of natural resources
  - Complementary for industrialization (e.g., Coal & Steam engine)
Variations in Country-Specific Characteristics Conducive for Technological Progress

\[ e_{t+1}^i = e(g_{t+1}; \Psi) \]
\[ g_{t+1}^B = g(e_t; L, \Omega^B) \]
\[ g_{t+1}^A = g(e_t; L, \Omega^A) \]
Earlier Take-off in Country B

\[
\begin{align*}
\hat{g}(\Psi) & \quad g^A(0; L, \Omega^A) \\
& \quad g^B(0; L, \Omega^B) \\
& \quad g^H(L, \Omega^B, \Psi) \\
\end{align*}
\]

\[
\begin{align*}
e_{t+1}^i &= e(g_{t+1}; \Psi) \\
g_{t+1}^B &= g(e_t; L, \Omega^B) \\
g_{t+1}^A &= g(e_t; L, \Omega^A) \\
\end{align*}
\]
Variation in Characteristics Conducive for Human Capital Formation

- For country-specific characteristics $\Psi^i_t$
Variation in Characteristics Conducive for Human Capital Formation

For country-specific characteristics $\Psi^i_t$

$$e^i_{t+1} = e(g^i_{t+1}; \Psi^i_t) \begin{cases} 
= 0 & \text{if } g^i_{t+1} \leq \hat{g}(\Psi^i_t), \\
> 0 & \text{if } g^i_{t+1} > \hat{g}(\Psi^i_t)
\end{cases}$$
Variation in Characteristics Conducive for Human Capital Formation

- Ability of individuals to finance the cost of education and the forgone earnings
  - Extent of human capital formation
Variation in Characteristics Conducive for Human Capital Formation

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  - Productivity of human capital formation
Variation in Characteristics Conducive for Human Capital Formation

- The propensity of a country to trade
  - Skill-intensity in production and its effect on the demand for human capital
Variation in Characteristics Conducive for Human Capital Formation

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- The effect of geographical attributes on health
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- Social status associated with education
Variation in Characteristics Conducive for Human Capital Formation

\[ e_{t+1}^A = e(g_{t+1}^A; \Psi^A) \]

\[ e_{t+1}^B = e(g_{t+1}^B; \Psi^B) \]

\[ g_{t+1}^i = g(e_t^i; L, \Omega) \]
Earlier Take-off in Country B

\[ e_{t+1}^A = e(g_{t+1}^A; \Psi^A) \]

\[ e_{t+1}^B = e(g_{t+1}^B; \Psi^B) \]

\[ g_{t+1}^i = g(e_t^i; L, \Omega) \]

\[ g^H(L, \Omega, \Psi^B) \]

\[ \hat{g}(\Psi^A) \]

\[ g^A(0; L, \Omega) \]

\[ \hat{g}(\Psi^B) \]
Concluding Remarks

- UGT suggests that:

  The transition from stagnation to growth was an inevitable by-product of the process of development. The inherent Malthusian interaction between technology and population accelerated the pace of technological progress, and eventually brought an industrial demand for human capital. Human capital formation triggered a demographic transition, enabling economies to convert a larger share of the fruits of factor accumulation and technological progress into growth of income per capita. Variations in the timing of the take-off contributed significantly to the divergence in income per capita in the past two centuries.
Concluding Remarks

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- UGT sheds light on:

  1. The historical origins of vast and persistent inequality across countries
  2. The forces that triggered the transition of DCs from stagnation to growth
  3. The hurdles faced by LDCs in their take-off from stagnation to growth
  4. The factors that hindered convergence across countries
  5. The role of deep rooted factors in comparative development
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