The Malthusian Hypothesis

Oded Galor

October 26, 2019

Two Mysteries

- The Mystery of Growth:

Two Mysteries

- The Mystery of Growth:
  - Why economic growth emerged only in the past two centuries, after hundreds of thousands of years of stagnation?

Two Mysteries

- The Mystery of Growth:
  - Why economic growth emerged only in the past two centuries, after hundreds of thousands of years of stagnation?
- The Mystery of the Gaps

Two Mysteries

- The Mystery of Growth:
  - Why economic growth emerged only in the past two centuries, after hundreds of thousands of years of stagnation?
- The Mystery of the Gaps
  - What is the origin of the vast inequality in income per capita across countries and regions?

Resolution of these Mysteries

- Requires the identification of the Malthusian forces:

Resolution of these Mysteries

- Requires the identification of the Malthusian forces:
  - Triggered the transition from stagnation to growth

Resolution of these Mysteries

- Requires the identification of the Malthusian forces:
  - Triggered the transition from stagnation to growth
  - The differential timing of the transition across the globe

Resolution of these Mysteries

- Requires the identification of the Malthusian forces:
  - Triggered the transition from stagnation to growth
  - The differential timing of the transition across the globe
  - The role of historical pre-historical factors in this process

Resolution of these Mysteries

- Requires the identification of the Malthusian forces:
  - Triggered the transition from stagnation to growth
  - The differential timing of the transition across the globe
  - The role of historical pre-historical factors in this process
  - The contribution of evolutionary forces in this process

Historical Evidence

- Forces that operated in the distant past contributed to:

Historical Evidence

- Forces that operated in the distant past contributed to:
  - The timing of the transition from stagnation to growth

Historical Evidence

- Forces that operated in the distant past contributed to:
  - The timing of the transition from stagnation to growth
  - The vast inequality across countries and regions

Historical Evidence

- Forces that operated in the distant past contributed to:
  - The timing of the transition from stagnation to growth
  - The vast inequality across countries and regions
- The Malthusian epoch is key to the resolution of the two mysteries

Phases of Development

- The Malthusian Epoch

Phases of Development

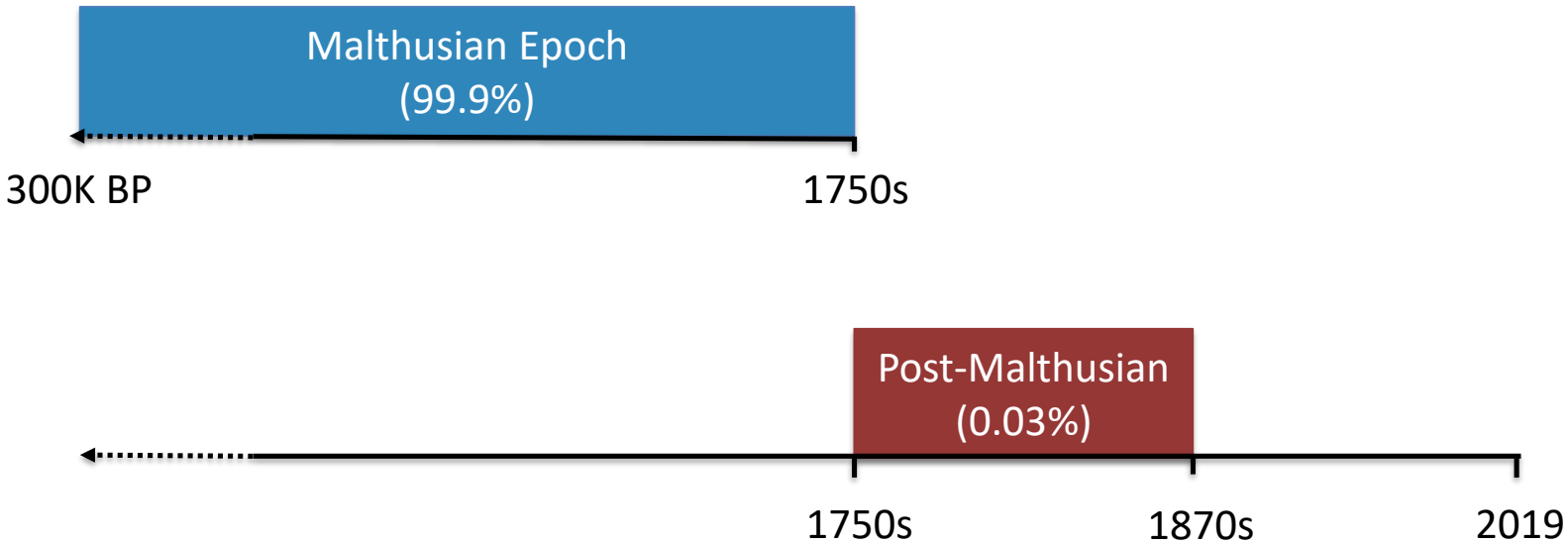
- The Malthusian Epoch
- The Post-Malthusian Regime

Phases of Development

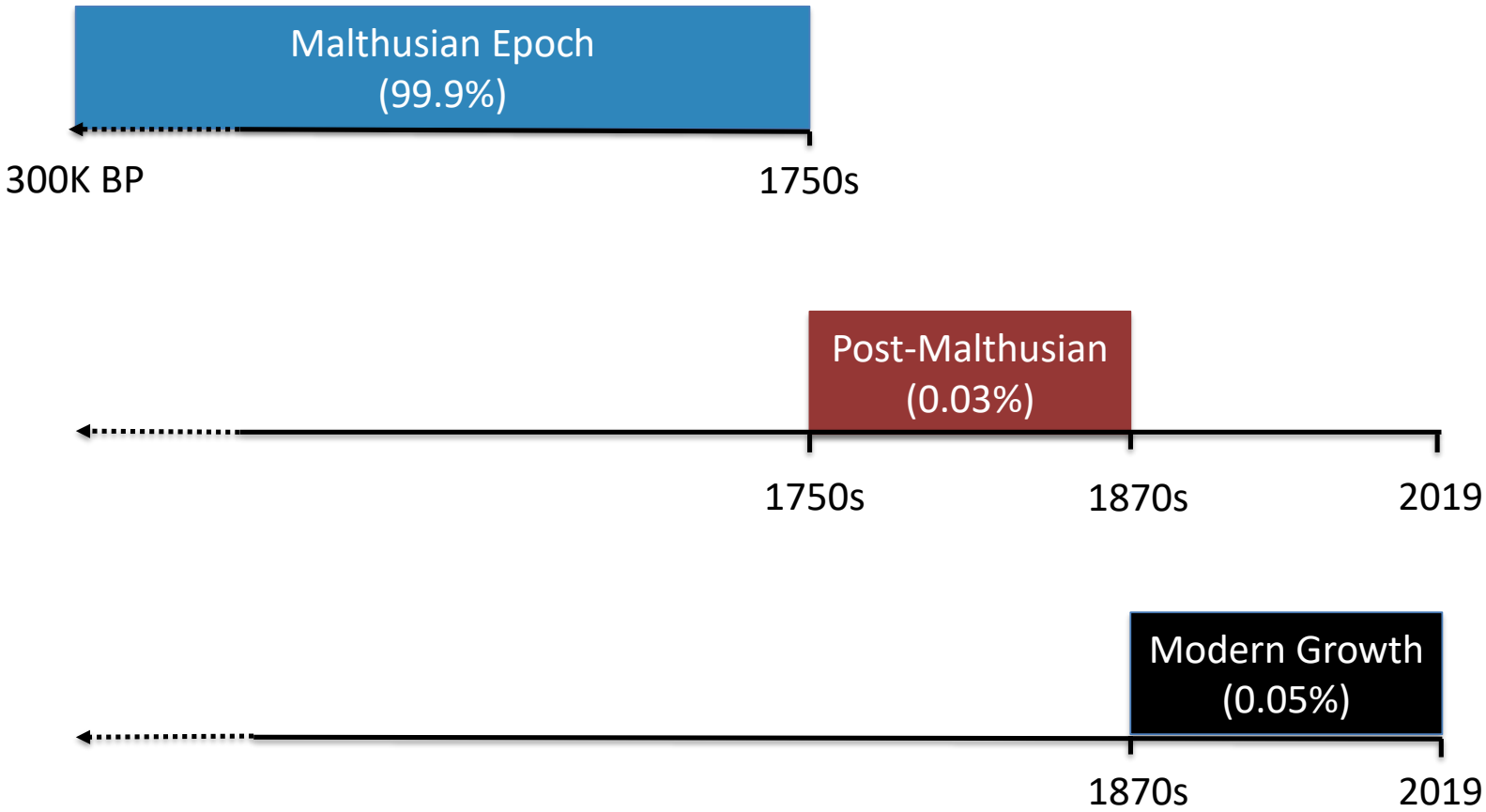
- The Malthusian Epoch
- The Post-Malthusian Regime
- The Modern Growth Regime

Phases of Development: Timeline of the Most Developed Economies

Phases of Development: Timeline of the Most Developed Economies



Phases of Development: Timeline of the Most Developed Economies



The Malthusian Epoch

- Dualism: Stagnation & Dynamism:

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range
    - Life expectancy: trendless fluctuation in the range of 25-40 years

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range
    - Life expectancy: trendless fluctuation in the range of 25-40 years
  - Dynamism:

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range
    - Life expectancy: trendless fluctuation in the range of 25-40 years
  - Dynamism:
    - Technological progress

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range
    - Life expectancy: trendless fluctuation in the range of 25-40 years
  - Dynamism:
    - Technological progress
    - Population growth

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range
    - Life expectancy: trendless fluctuation in the range of 25-40 years
  - Dynamism:
    - Technological progress
    - Population growth
    - Evolution: (biological or cultural) adaptation of human traits

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range
    - Life expectancy: trendless fluctuation in the range of 25-40 years
  - Dynamism:
    - Technological progress
    - Population growth
    - Evolution: (biological or cultural) adaptation of human traits
  - Malthusian dynamism

The Malthusian Epoch

- Dualism: Stagnation & Dynamism:
  - Stagnation in living standards:
    - Income per capita: trendless fluctuation in a narrow range
    - Life expectancy: trendless fluctuation in the range of 25-40 years
  - Dynamism:
    - Technological progress
    - Population growth
    - Evolution: (biological or cultural) adaptation of human traits
  - Malthusian dynamism
    - Ultimately triggered the transition from stagnation to growth

The Malthusian Epoch

- Central characteristics of the period:

The Malthusian Epoch

- Central characteristics of the period:
  - Positive effect of income on population growth (via reduction in child mortality, increase in fertility & life expectancy)

The Malthusian Epoch

- Central characteristics of the period:
  - Positive effect of income on population growth (via reduction in child mortality, increase in fertility & life expectancy)
    - $y \uparrow \Longrightarrow L \uparrow$

The Malthusian Epoch

- Central characteristics of the period:
  - Positive effect of income on population growth (via reduction in child mortality, increase in fertility & life expectancy)
    - $y \uparrow \Longrightarrow L \uparrow$
  - Diminishing returns to labor: (due to land constraint)

The Malthusian Epoch

- Central characteristics of the period:
  - Positive effect of income on population growth (via reduction in child mortality, increase in fertility & life expectancy)
    - $y \uparrow \Longrightarrow L \uparrow$
  - Diminishing returns to labor: (due to land constraint)
    - $L \uparrow \Longrightarrow AP_L \downarrow$

Malthusian Dynamics

- Technological progress during the Malthusian epoch

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)
  - Population adjust, as long as income remains above subsistence

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)
  - Population adjust, as long as income remains above subsistence
    - $y \uparrow \implies L \uparrow$

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)
  - Population adjust, as long as income remains above subsistence
    - $y \uparrow \implies L \uparrow$
  - Income per capita ultimately returns to its long-run level

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)
  - Population adjust, as long as income remains above subsistence
    - $y \uparrow \implies L \uparrow$
  - Income per capita ultimately returns to its long-run level
    - $L \uparrow \implies AP_L \downarrow \implies y \downarrow$

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)
  - Population adjust, as long as income remains above subsistence
    - $y \uparrow \implies L \uparrow$
  - Income per capita ultimately returns to its long-run level
    - $L \uparrow \implies AP_L \downarrow \implies y \downarrow$
- Technologically advanced & land-rich economies:

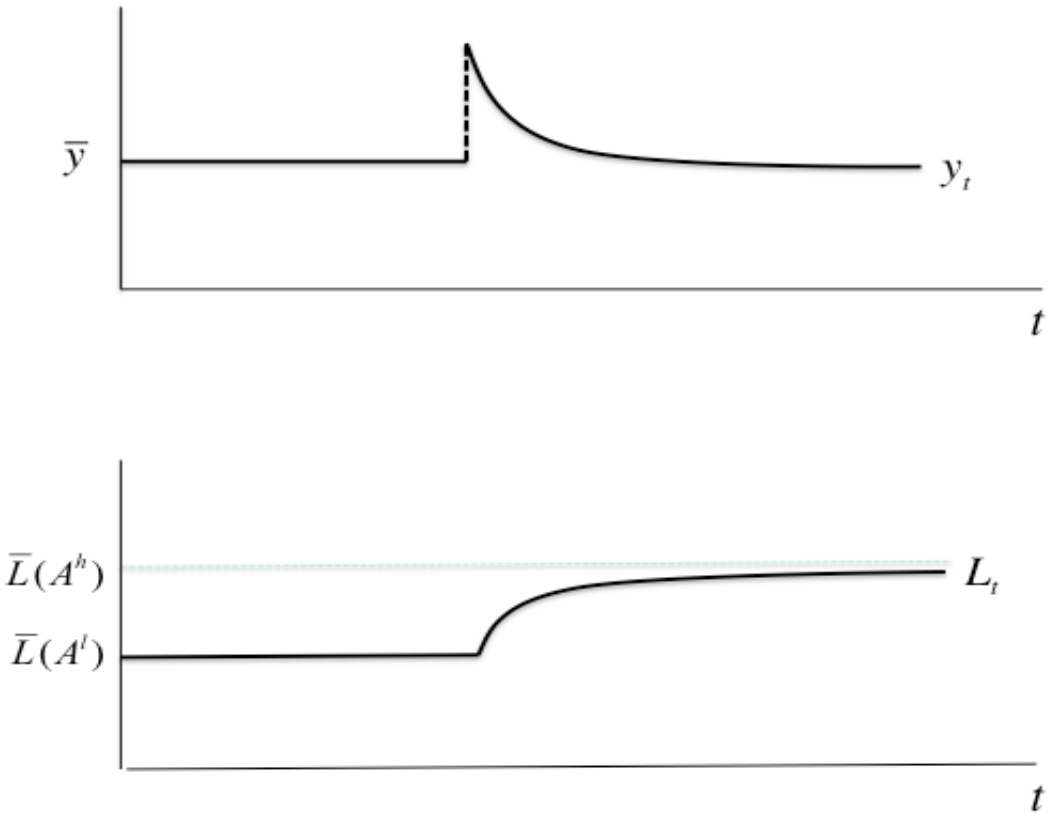
Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)
  - Population adjust, as long as income remains above subsistence
    - $y \uparrow \implies L \uparrow$
  - Income per capita ultimately returns to its long-run level
    - $L \uparrow \implies AP_L \downarrow \implies y \downarrow$
- Technologically advanced & land-rich economies:
  - Higher population density

Malthusian Dynamics

- Technological progress during the Malthusian epoch
  - Increases income per capita in the very short-run
    - $A \uparrow \implies y \uparrow$ (above subsistence)
  - Population adjust, as long as income remains above subsistence
    - $y \uparrow \implies L \uparrow$
  - Income per capita ultimately returns to its long-run level
    - $L \uparrow \implies AP_L \downarrow \implies y \downarrow$
- Technologically advanced & land-rich economies:
  - Higher population density
  - Similar levels of income per-capita in the long-run

Malthusian Dynamics



Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)

Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the adoption of a new world crop – potato

Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the adoption of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1910)

Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the adoption of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1910)
  - Triggered by superior agricultural technology & adoption of Maize

Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the adoption of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1910)
  - Triggered by superior agricultural technology & adoption of Maize
- The dynamics of the English economy (1348 - 1700)

Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the adoption of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1910)
  - Triggered by superior agricultural technology & adoption of Maize
- The dynamics of the English economy (1348 - 1700)
  - Triggered by the Black Death

Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange $\Longrightarrow$ massive cultivation of potato post-1650

Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange $\Longrightarrow$ massive cultivation of potato post-1650
  - 1650-1840s

Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange $\Longrightarrow$ massive cultivation of potato post-1650
  - 1650-1840s
    - Population grew from 2 to 6 million

Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange $\Longrightarrow$ massive cultivation of potato post-1650
  - 1650-1840s
    - Population grew from 2 to 6 million
    - Income per capita increased only very modestly

Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange $\Longrightarrow$ massive cultivation of potato post-1650
  - 1650-1840s
    - Population grew from 2 to 6 million
    - Income per capita increased only very modestly
  - 1845-1852 Potato blight destroys crops $\Longrightarrow$ Great Famine

Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange $\Longrightarrow$ massive cultivation of potato post-1650
  - 1650-1840s
    - Population grew from 2 to 6 million
    - Income per capita increased only very modestly
  - 1845-1852 Potato blight destroys crops $\Longrightarrow$ Great Famine
    - Population declined by about 2 million (Death & Emigration)

Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange $\Longrightarrow$ massive cultivation of potato post-1650
  - 1650-1840s
    - Population grew from 2 to 6 million
    - Income per capita increased only very modestly
  - 1845-1852 Potato blight destroys crops $\Longrightarrow$ Great Famine
    - Population declined by about 2 million (Death & Emigration)
    - Income per capita remained nearly unchanged

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820
    - Population increased from 103 to 381 million

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820
    - Population increased from 103 to 381 million
    - Share of China in world population increased from 23% to 37%

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820
    - Population increased from 103 to 381 million
    - Share of China in world population increased from 23% to 37%
    - Income per capita was steady at $600

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820
    - Population increased from 103 to 381 million
    - Share of China in world population increased from 23% to 37%
    - Income per capita was steady at $600
- Adoption of Maize (Chen and Kung, JOEG 2016)

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820
    - Population increased from 103 to 381 million
    - Share of China in world population increased from 23% to 37%
    - Income per capita was steady at $600
- Adoption of Maize (Chen and Kung, JOEG 2016)
  - 1776-1910

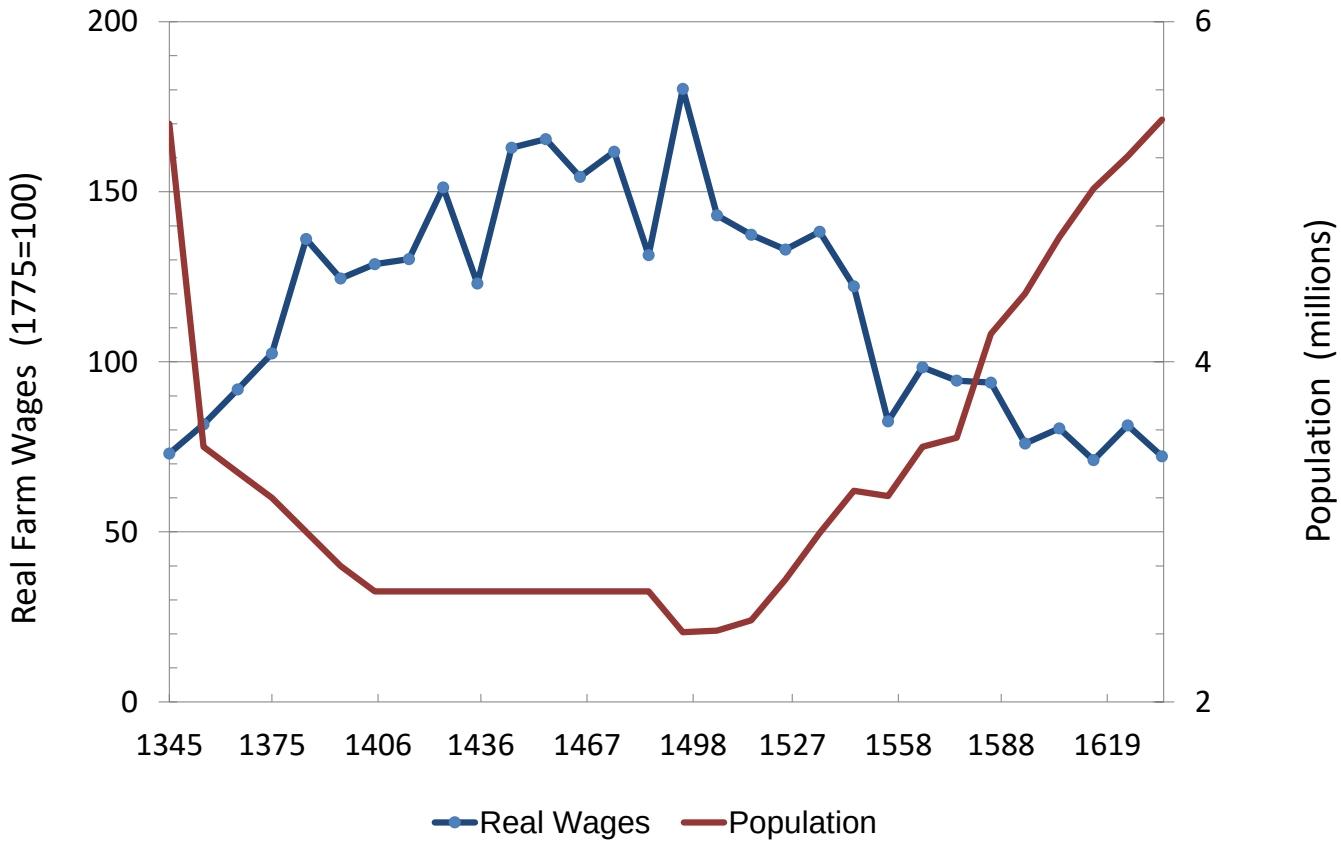
Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820
    - Population increased from 103 to 381 million
    - Share of China in world population increased from 23% to 37%
    - Income per capita was steady at $600
- Adoption of Maize (Chen and Kung, JOEG 2016)
  - 1776-1910
    - Contributed to 1/5 of China's population growth over the period

Malthusian Dynamics - China (1500 - 1910)

- Superior agricultural technology
  - 1500-1820
    - Population increased from 103 to 381 million
    - Share of China in world population increased from 23% to 37%
    - Income per capita was steady at $600
- Adoption of Maize (Chen and Kung, JOEG 2016)
  - 1776-1910
    - Contributed to 1/5 of China's population growth over the period
    - No impact on income per capita (real wages)

Malthusian Adjustments to the Black Death: England, 1348–1635



Length of the Malthusian Adjustment Period

- Black Death:

Length of the Malthusian Adjustment Period

- Black Death:
  - 300 years

Length of the Malthusian Adjustment Period

- Black Death:
  - 300 years
- 1609 Spanish expulsion of 300K converted Muslims (Moriscos):

Length of the Malthusian Adjustment Period

- Black Death:
  - 300 years
- 1609 Spanish expulsion of 300K converted Muslims (Moriscos):
  - 180 years (Chaney and Hornbeck, EJ 2016)

The Basic Structure of the Model

- Overlapping-generations economy

The Basic Structure of the Model

- Overlapping-generations economy
- $t = 0, 1, 2, 3...$

The Basic Structure of the Model

- Overlapping-generations economy
- $t = 0, 1, 2, 3...$
- One homogeneous good

The Basic Structure of the Model

- Overlapping-generations economy
- $t = 0, 1, 2, 3...$
- One homogeneous good
- 2 factors of production:

The Basic Structure of the Model

- Overlapping-generations economy
- $t = 0, 1, 2, 3...$
- One homogeneous good
- 2 factors of production:
  - Labor

The Basic Structure of the Model

- Overlapping-generations economy
- $t = 0, 1, 2, 3...$
- One homogeneous good
- 2 factors of production:
  - Labor
  - Land

Production

- The output produced in period t

$$Y_t =$$

Production

- The output produced in period t

$$Y_t =$$

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t
  - $X \equiv$ land

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t
  - $X \equiv$ land
  - $A \equiv$ technological level

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t
  - $X \equiv$ land
  - $A \equiv$ technological level
  - $AX \equiv$ effective resources

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t
  - $X \equiv$ land
  - $A \equiv$ technological level
  - $AX \equiv$ effective resources

- Output per worker produced at time t

$$y_t =$$

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t
  - $X \equiv$ land
  - $A \equiv$ technological level
  - $AX \equiv$ effective resources

- Output per worker produced at time t

$$y_t =$$

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t
  - $X \equiv$ land
  - $A \equiv$ technological level
  - $AX \equiv$ effective resources

- Output per worker produced at time t

$$y_t = \frac{Y_t}{L_t} =$$

Production

- The output produced in period t

$$Y_t = (AX)^{\alpha} L_t^{1-\alpha} \qquad 0 < \alpha < 1$$

  - $L_t \equiv$ working population (labor) in period t
  - $X \equiv$ land
  - $A \equiv$ technological level
  - $AX \equiv$ effective resources

- Output per worker produced at time t

$$y_t = \frac{Y_t}{L_t} = \left[\frac{AX}{L_t}\right]^{\alpha}$$

Supply of Factors of Production

- Land is fixed over time

Supply of Factors of Production

- Land is fixed over time
  - Surface of planet earth

Supply of Factors of Production

- Land is fixed over time
  - Surface of planet earth
- Labor evolves endogenously

Supply of Factors of Production

- Land is fixed over time
  - Surface of planet earth
- Labor evolves endogenously
  - Determined by households' fertility rate

Individuals

- Live for 2 period

Individuals

- Live for 2 period
  - Childhood: (1st Period):

Individuals

- Live for 2 period
  - Childhood: (1st Period):
    - Passive economic agents

Individuals

- Live for 2 period
  - Childhood: (1st Period):
    - Passive economic agents
    - Consume fixed amount of their parental resources

Individuals

- Live for 2 period
  - Childhood: (1st Period):
    - Passive economic agents
    - Consume fixed amount of their parental resources
  - Adulthood (2nd Period):

Individuals

- Live for 2 period
  - Childhood: (1st Period):
    - Passive economic agents
    - Consume fixed amount of their parental resources
  - Adulthood (2nd Period):
    - Work

Individuals

- Live for 2 period
  - Childhood: (1st Period):
    - Passive economic agents
    - Consume fixed amount of their parental resources
  - Adulthood (2nd Period):
    - Work
    - Allocate income between consumption and children

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t =$$

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t =$$

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t = (n_t)^{\gamma}(c_t)^{1-\gamma} \qquad 0 < \gamma < 1$$

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t = (n_t)^{\gamma}(c_t)^{1-\gamma} \qquad 0 < \gamma < 1$$

  - $n_t \equiv$ number of children of individual t

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t = (n_t)^{\gamma}(c_t)^{1-\gamma} \qquad 0 < \gamma < 1$$

  - $n_t \equiv$ number of children of individual t
  - $c_t \equiv$ consumption of individual t

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t = (n_t)^{\gamma}(c_t)^{1-\gamma} \qquad 0 < \gamma < 1$$

  - $n_t \equiv$ number of children of individual t
  - $c_t \equiv$ consumption of individual t

- Budget constraint:

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t = (n_t)^{\gamma}(c_t)^{1-\gamma} \qquad 0 < \gamma < 1$$

  - $n_t \equiv$ number of children of individual t
  - $c_t \equiv$ consumption of individual t

- Budget constraint:

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t = (n_t)^{\gamma}(c_t)^{1-\gamma} \qquad 0 < \gamma < 1$$

  - $n_t \equiv$ number of children of individual t
  - $c_t \equiv$ consumption of individual t

- Budget constraint:

$$\rho n_t + c_t \leq y_t$$

Preferences and Budget Constraint

- Preferences of an adult at time t

$$U_t = (n_t)^{\gamma}(c_t)^{1-\gamma} \qquad 0 < \gamma < 1$$

  - $n_t \equiv$ number of children of individual t
  - $c_t \equiv$ consumption of individual t

- Budget constraint:

$$\rho n_t + c_t \leq y_t$$

  - $\rho \equiv$ cost of raising a child

Optimization

- Optimal expenditure on consumption and children

Optimization

- Optimal expenditure on consumption and children

Optimization

- Optimal expenditure on consumption and children

$$c_t =$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1 - \gamma)$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t =$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t = \gamma$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t = \gamma y_t$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t = \gamma y_t$$

- Desirable number of children

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t = \gamma y_t$$

- Desirable number of children

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t = \gamma y_t$$

- Desirable number of children

$$n_t$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t = \gamma y_t$$

- Desirable number of children

$$n_t = \frac{\gamma}{\rho}$$

Optimization

- Optimal expenditure on consumption and children

$$c_t = (1-\gamma)y_t$$

$$\rho n_t = \gamma y_t$$

- Desirable number of children

$$n_t = \frac{\gamma}{\rho} y_t$$

Population Dynamics

- The evolution of the size of the working population

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} =$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

- Population dynamics:

$$L_{t+1} =$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

- Population dynamics:

$$L_{t+1} = \frac{\gamma}{\rho} y_t$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

- Population dynamics:

$$L_{t+1} = \frac{\gamma}{\rho} y_t L_t$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

- Population dynamics:

$$L_{t+1} = \frac{\gamma}{\rho} y_t L_t = \frac{\gamma}{\rho} Y_t$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

- Population dynamics:

$$L_{t+1} = \frac{\gamma}{\rho} y_t L_t = \frac{\gamma}{\rho} Y_t = \frac{\gamma}{\rho}$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

- Population dynamics:

$$L_{t+1} = \frac{\gamma}{\rho} y_t L_t = \frac{\gamma}{\rho} Y_t = \frac{\gamma}{\rho} (AX)^{\alpha} L_t^{1-\alpha}$$

Population Dynamics

- The evolution of the size of the working population

$$L_{t+1} = n_t L_t$$

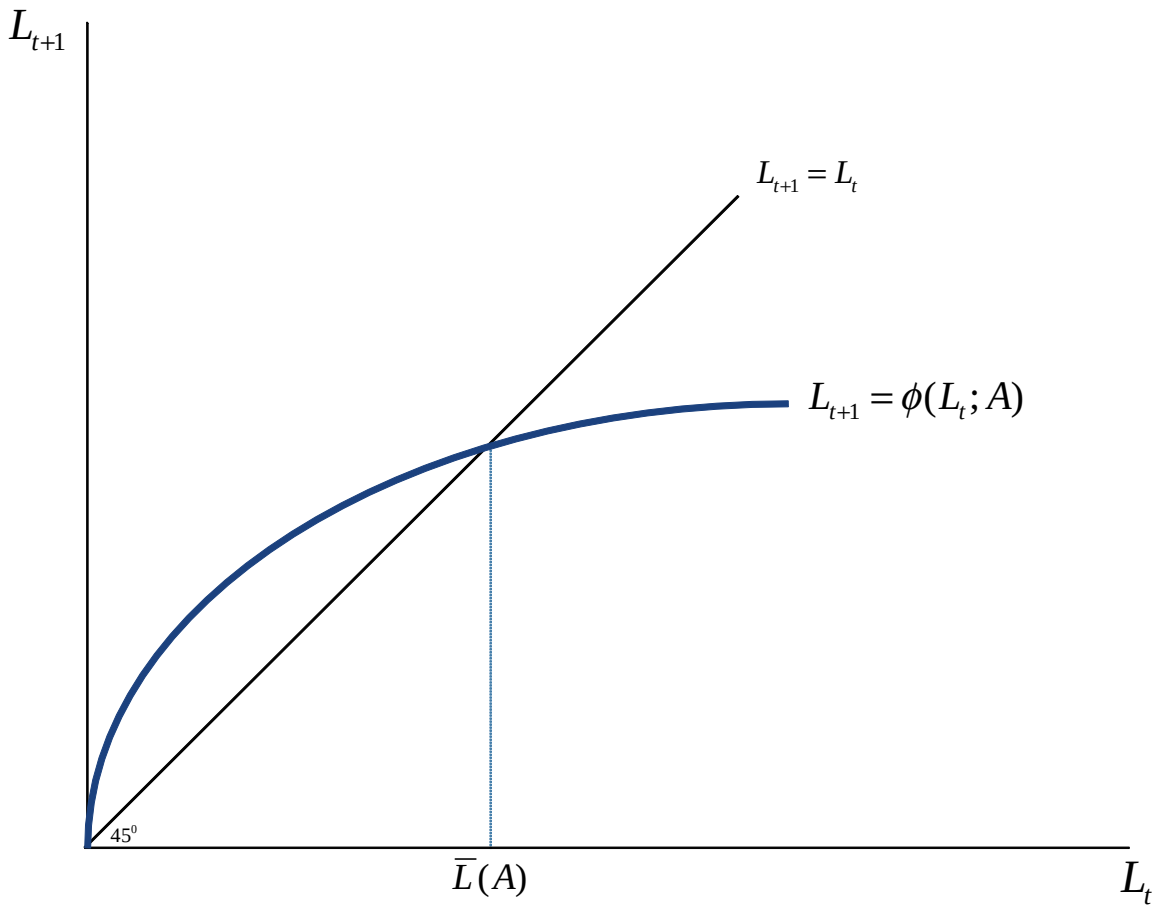
where

$$n_t = \frac{\gamma}{\rho} y_t$$

- Population dynamics:

$$L_{t+1} = \frac{\gamma}{\rho} y_t L_t = \frac{\gamma}{\rho} Y_t = \frac{\gamma}{\rho} (AX)^{\alpha} L_t^{1-\alpha} \equiv \phi(L_t; A)$$

Population Dynamics



The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha}L_t^{1-\alpha} \equiv \phi(L_t; A)$$

The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha}L_t^{1-\alpha} \equiv \phi(L_t; A)$$

- Steady-State: $L_{t+1} = L_t = \bar{L}$

The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha}L_t^{1-\alpha} \equiv \phi(L_t; A)$$

- Steady-State: $L_{t+1} = L_t = \bar{L}$

$$\bar{L} =$$

The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha} L_t^{1-\alpha} \equiv \phi(L_t; A)$$

- Steady-State: $L_{t+1} = L_t = \bar{L}$

$$\bar{L} = \frac{\gamma}{\rho}(AX)^{\alpha}$$

The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha} L_t^{1-\alpha} \equiv \phi(L_t; A)$$

- Steady-State: $L_{t+1} = L_t = \bar{L}$

$$\bar{L} = \frac{\gamma}{\rho}(AX)^{\alpha} \bar{L}^{1-\alpha}$$

The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha} L_t^{1-\alpha} \equiv \phi(L_t; A)$$

- Steady-State: $L_{t+1} = L_t = \bar{L}$

$$\bar{L} = \frac{\gamma}{\rho}(AX)^{\alpha} \bar{L}^{1-\alpha}$$

- The steady-state level of the size of the working population

$$\bar{L} =$$

The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha} L_t^{1-\alpha} \equiv \phi(L_t; A)$$

- Steady-State: $L_{t+1} = L_t = \bar{L}$

$$\bar{L} = \frac{\gamma}{\rho}(AX)^{\alpha} \bar{L}^{1-\alpha}$$

- The steady-state level of the size of the working population

$$\bar{L} = \left(\frac{\gamma}{\rho}\right)^{1/\alpha}(AX)$$

The Steady-State Level of Population

- The evolution of the size of the working population

$$L_{t+1} = \frac{\gamma}{\rho}(AX)^{\alpha} L_t^{1-\alpha} \equiv \phi(L_t; A)$$

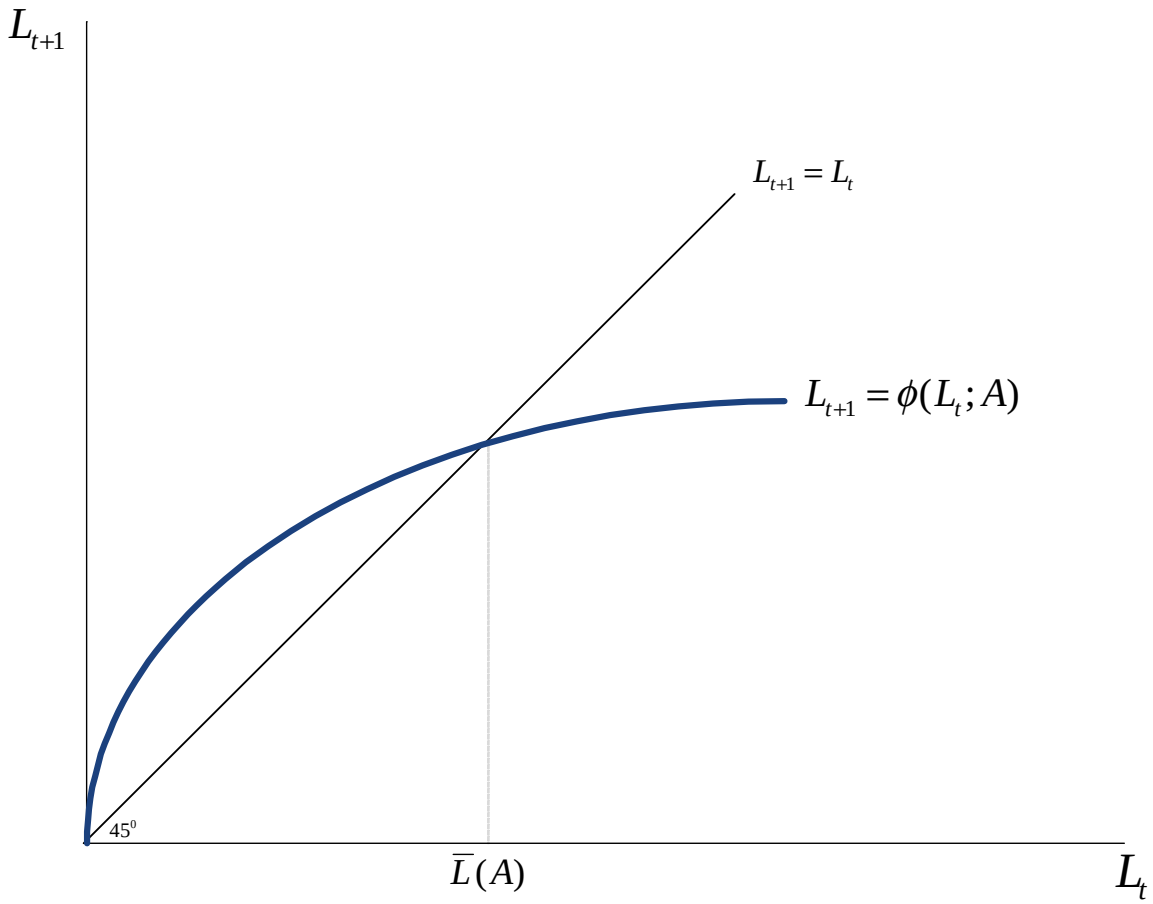
- Steady-State: $L_{t+1} = L_t = \bar{L}$

$$\bar{L} = \frac{\gamma}{\rho}(AX)^{\alpha} \bar{L}^{1-\alpha}$$

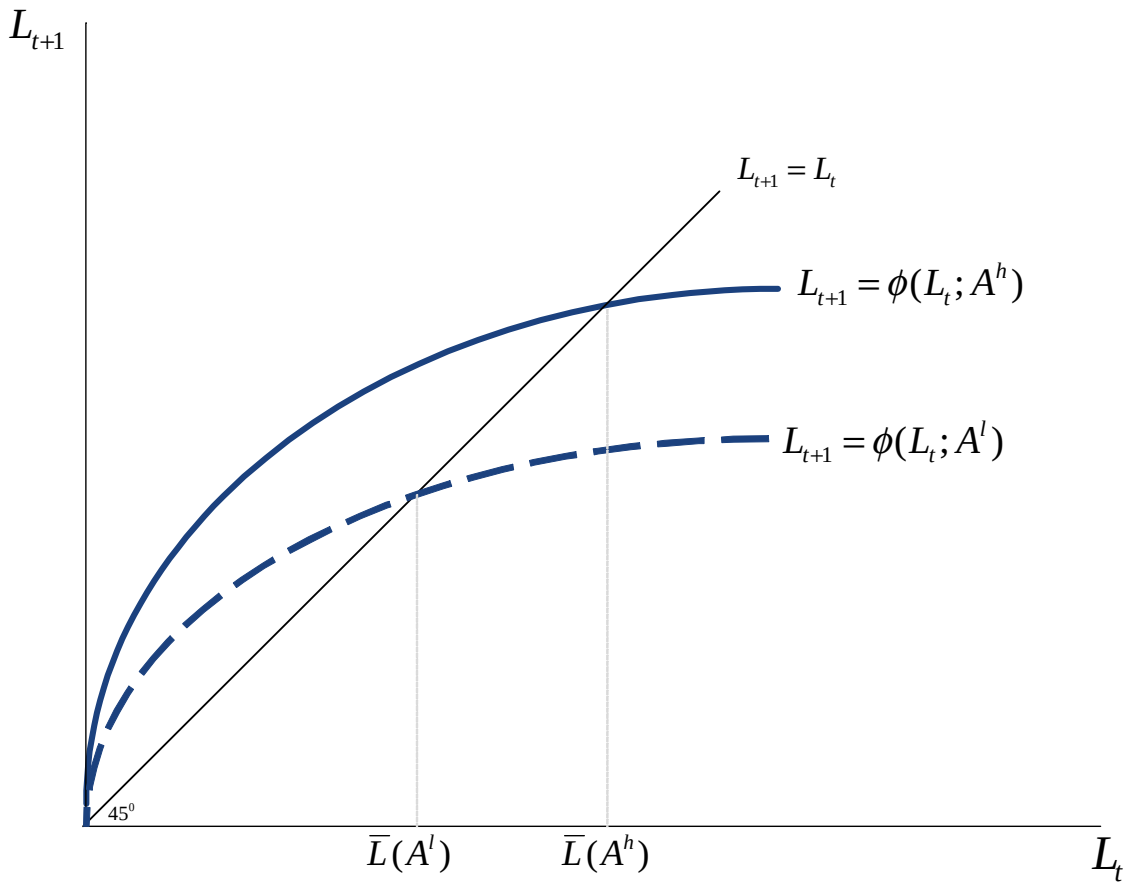
- The steady-state level of the size of the working population

$$\bar{L} = (\frac{\gamma}{\rho})^{1/\alpha}(AX) \equiv \bar{L}(A)$$

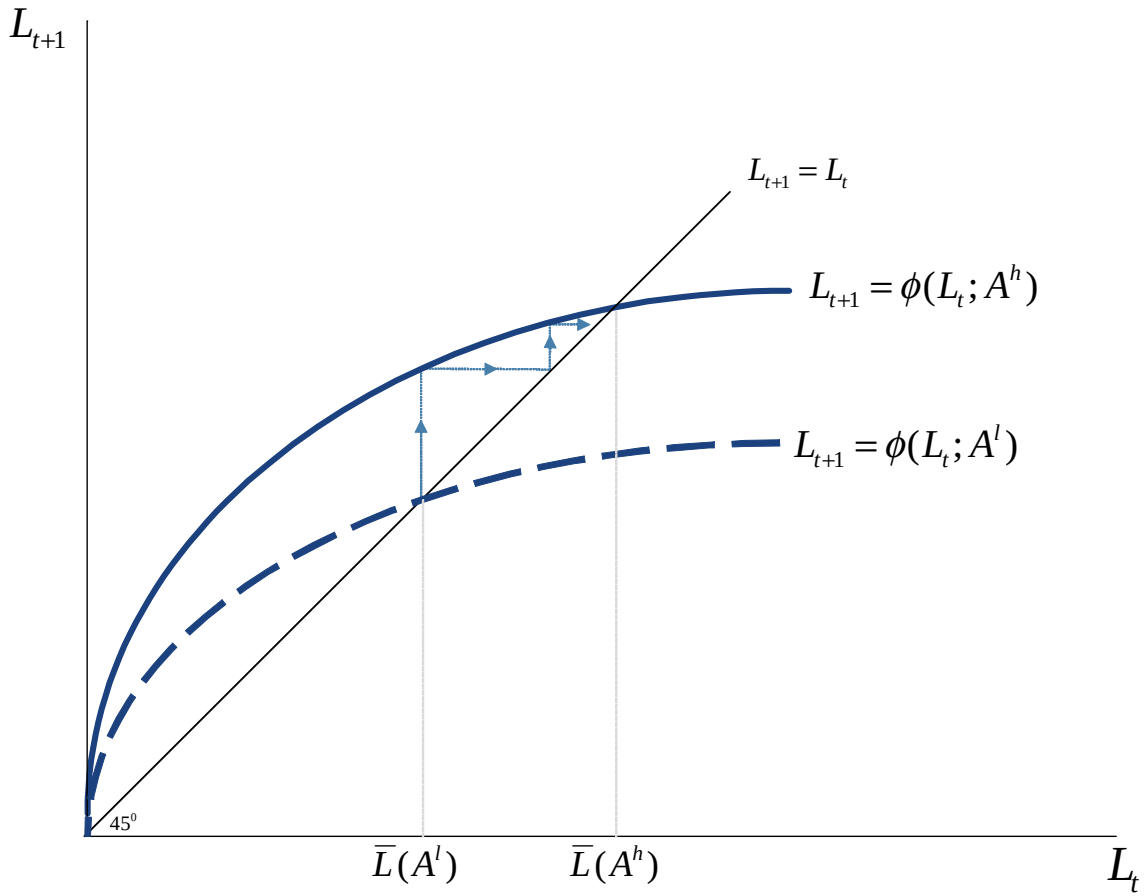
Population Dynamics



Adjustment of Population to Advancements in Technology



Adjustment of Population to Advancements in Technology



The Evolution of Income per Worker

- The time path of income per worker

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} =$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha}$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha}$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

$\Longrightarrow$

$$y_{t+1} =$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

$\Longrightarrow$

$$y_{t+1} = \frac{y_t}{n_t^{\alpha}} =$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

$$\Longrightarrow$$

$$y_{t+1} = \frac{y_t}{n_t^{\alpha}} = \frac{y_t}{\left[\frac{\gamma}{\rho}\right]^{\alpha} y_t^{\alpha}}$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

$$\Longrightarrow$$

$$y_{t+1} = \frac{y_t}{n_t^{\alpha}} = \frac{y_t}{\left[\frac{\gamma}{\rho}\right]^{\alpha} y_t^{\alpha}}$$

- Dynamics of income per worker

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

$$\Longrightarrow$$

$$y_{t+1} = \frac{y_t}{n_t^{\alpha}} = \frac{y_t}{\left[\frac{\gamma}{\rho}\right]^{\alpha} y_t^{\alpha}}$$

- Dynamics of income per worker

$$y_{t+1} =$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

$$\Longrightarrow$$

$$y_{t+1} = \frac{y_t}{n_t^{\alpha}} = \frac{y_t}{\left[\frac{\gamma}{\rho}\right]^{\alpha} y_t^{\alpha}}$$

- Dynamics of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha}$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

$$\Longrightarrow$$

$$y_{t+1} = \frac{y_t}{n_t^{\alpha}} = \frac{y_t}{\left[\frac{\gamma}{\rho}\right]^{\alpha} y_t^{\alpha}}$$

- Dynamics of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

The Evolution of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{AX}{L_{t+1}}\right]^{\alpha} = \left[\frac{AX}{n_t L_t}\right]^{\alpha} = \frac{y_t}{n_t^{\alpha}}$$

where

$$n_t = \frac{\gamma}{\rho} y_t$$

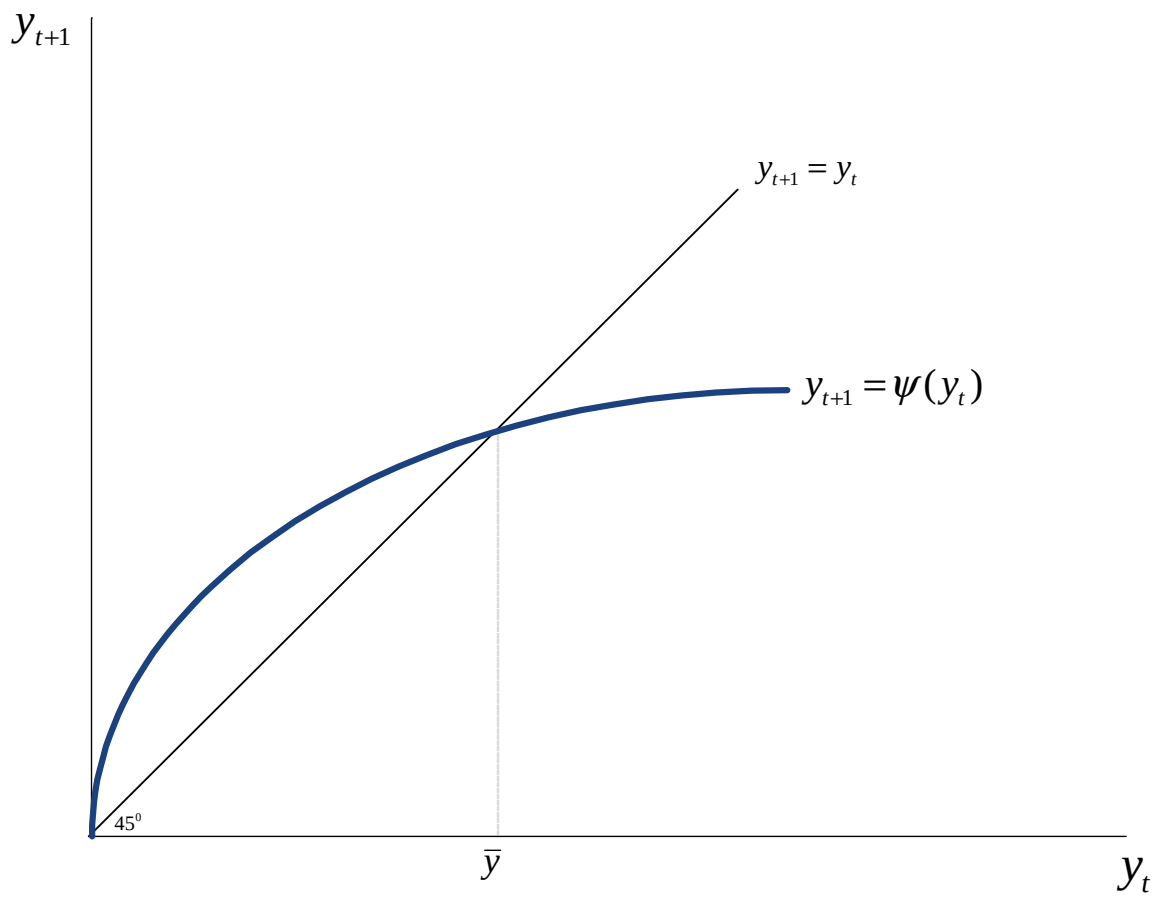
$$\Longrightarrow$$

$$y_{t+1} = \frac{y_t}{n_t^{\alpha}} = \frac{y_t}{\left[\frac{\gamma}{\rho}\right]^{\alpha} y_t^{\alpha}}$$

- Dynamics of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha} \equiv \psi(y_t)$$

The Evolution of Income per Worker



The Steady-State Level of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

The Steady-State Level of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

- Steady-State $y_{t+1} = y_t = \bar{y}$

$$\bar{y} =$$

The Steady-State Level of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

- Steady-State $y_{t+1} = y_t = \bar{y}$

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]^{\alpha} \bar{y}^{1-\alpha}$$

The Steady-State Level of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

- Steady-State $y_{t+1} = y_t = \bar{y}$

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]^{\alpha} \bar{y}^{1-\alpha}$$

- The steady-state level of income per worker

$$\bar{y} =$$

The Steady-State Level of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

- Steady-State $y_{t+1} = y_t = \bar{y}$

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]^{\alpha} \bar{y}^{1-\alpha}$$

- The steady-state level of income per worker

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]$$

The Steady-State Level of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

- Steady-State $y_{t+1} = y_t = \bar{y}$

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]^{\alpha} \bar{y}^{1-\alpha}$$

- The steady-state level of income per worker

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]$$

- The steady-state level of fertility

$$\bar{n} = \frac{\gamma}{\rho}\bar{y} =$$

The Steady-State Level of Income per Worker

- The time path of income per worker

$$y_{t+1} = \left[\frac{\rho}{\gamma}\right]^{\alpha} y_t^{1-\alpha}$$

- Steady-State $y_{t+1} = y_t = \bar{y}$

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]^{\alpha} \bar{y}^{1-\alpha}$$

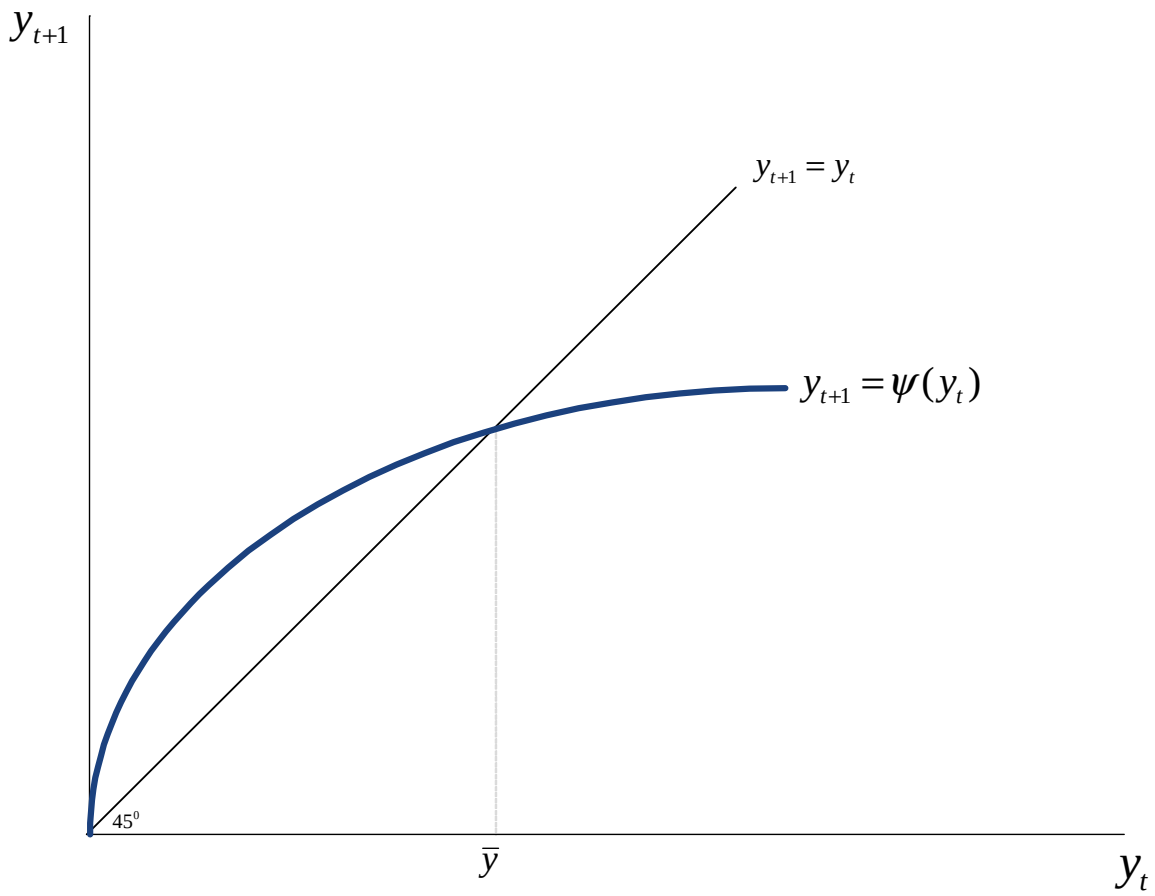
- The steady-state level of income per worker

$$\bar{y} = \left[\frac{\rho}{\gamma}\right]$$

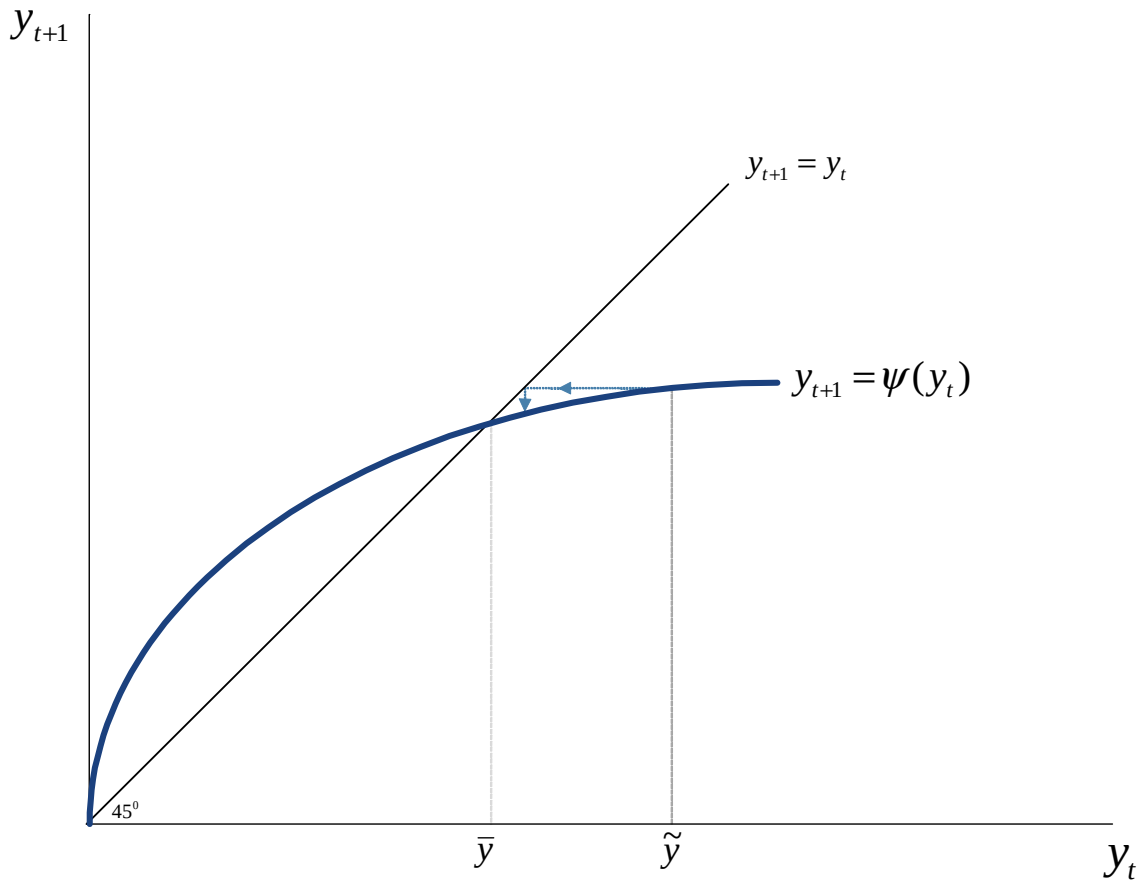
- The steady-state level of fertility

$$\bar{n} = \frac{\gamma}{\rho}\bar{y} = \left[\frac{\gamma}{\rho}\right]\left[\frac{\rho}{\gamma}\right] = 1$$

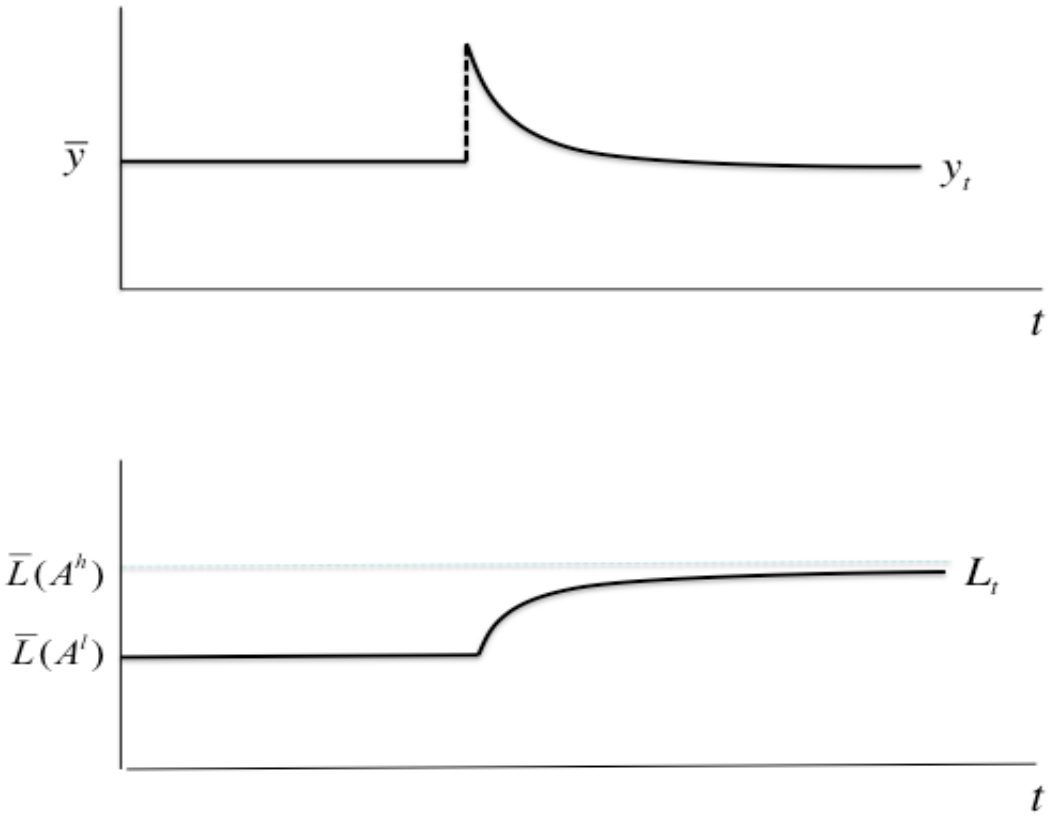
The Evolution of Income per Worker



The Effect of Technological Advancement on income per Worker



Technological Progress and the Time Path of Population & Income



Impact of Technological Progress or Land Productivity

- Increases the working population in the short-run and long-run

$$\frac{\partial L_t}{\partial A} > 0; \ \frac{\partial L_t}{\partial X} > 0; \ \frac{\partial \bar{L}}{\partial A} > 0; \ \frac{\partial \bar{L}}{\partial X} > 0;$$

- Increases income per worker in the short-run but not in the long-run

$$\frac{\partial y_t}{\partial A} > 0; \ \frac{\partial y_t}{\partial X} > 0; \ \frac{\partial \bar{y}}{\partial A} = 0; \frac{\partial \bar{y}}{\partial X} = 0$$

Testable Predictions

- Technological progress:

Testable Predictions

- Technological progress:
  - Higher population density

Testable Predictions

- Technological progress:
  - Higher population density
  - No effect on income per-capita in the long-run

Testable Predictions

- Technological progress:
  - Higher population density
  - No effect on income per-capita in the long-run
- Higher land quality:

Testable Predictions

- Technological progress:
  - Higher population density
  - No effect on income per-capita in the long-run
- Higher land quality:
  - Higher population density

Testable Predictions

- Technological progress:
  - Higher population density
  - No effect on income per-capita in the long-run
- Higher land quality:
  - Higher population density
  - No effect on income per-capita in the long-run

Objective

- Confirm (or refute) the Malthusian hypothesis:

Objective

- Confirm (or refute) the Malthusian hypothesis:
  - The causal effect of technology on Population

Objective

- Confirm (or refute) the Malthusian hypothesis:
  - The causal effect of technology on Population
  - The absence of an effect of technology on income per capita

Objective

- Confirm (or refute) the Malthusian hypothesis:
  - The causal effect of technology on Population
  - The absence of an effect of technology on income per capita
- Confirmation cannot rely on *correlation* between technology & population:

Objective

- Confirm (or refute) the Malthusian hypothesis:
  - The causal effect of technology on Population
  - The absence of an effect of technology on income per capita
- Confirmation cannot rely on *correlation* between technology & population:
  - Correlation $\nRightarrow$ Malthusian impact of technology on population

Objective

- Confirm (or refute) the Malthusian hypothesis:
  - The causal effect of technology on Population
  - The absence of an effect of technology on income per capita
- Confirmation cannot rely on *correlation* between technology & population:
  - Correlation $\not\Rightarrow$ Malthusian impact of technology on population
    - May reflect the impact of population on technology

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation

Correlation vs Causation - Examples

- Correlation $\nRightarrow$ Causation
  - Reverse Causality

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables

Correlation vs Causation - Examples

- Correlation $\nRightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]
    - [ice cream consumption] $\Rightarrow$ [people drown] ?

Correlation vs Causation - Examples

- Correlation $\nRightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]
    - [ice cream consumption] $\Rightarrow$ [people drown] ?
    - high temperature

Correlation vs Causation - Examples

- Correlation $\nRightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]
    - [ice cream consumption] $\Rightarrow$ [people drown] ?
    - high temperature

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]
    - [ice cream consumption] $\Rightarrow$ [people drown] ?
    - high temperature $\Rightarrow$ [ice cream consumption $\uparrow$]

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]
    - [ice cream consumption] $\Rightarrow$ [people drown] ?
    - high temperature $\Rightarrow$ [ice cream consumption $\uparrow$]
    - high temperature $\Rightarrow$ [swimming in sea $\uparrow$]

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]
    - [ice cream consumption] $\Rightarrow$ [people drown] ?
    - high temperature $\Rightarrow$ [ice cream consumption $\uparrow$]
    - high temperature $\Rightarrow$ [swimming in sea $\uparrow$]

Correlation vs Causation - Examples

- Correlation $\not\Rightarrow$ Causation
  - Reverse Causality
  - Omitted Variables
- Reverse Causality
  - Correlation between: [overweight people] & [people on diet]
    - Diet $\Rightarrow$ Overweight ?
    - Overweight $\Longrightarrow$ Diet
- Omitted Variables (3rd factor governs the correlation):
  - Correlation between: [ice cream consumption] & [people drown]
    - [ice cream consumption] $\Rightarrow$ [people drown] ?
    - high temperature $\Rightarrow$ [ice cream consumption $\uparrow$]
    - high temperature $\Rightarrow$ [swimming in sea $\uparrow$]$\Rightarrow$[people drown $\uparrow$]

Cross-Country Analysis

- Available Data

Cross-Country Analysis

- Available Data
  - Dependent Variables:

Cross-Country Analysis

- Available Data
  - Dependent Variables:
    - Income per capita in the years 1, 1000, 1500

Cross-Country Analysis

- Available Data
  - Dependent Variables:
    - Income per capita in the years 1, 1000, 1500
    - Population density in the years 1, 1000, 1500

Cross-Country Analysis

- Available Data
  - Dependent Variables:
    - Income per capita in the years 1, 1000, 1500
    - Population density in the years 1, 1000, 1500
  - Main Independent Variables:

Cross-Country Analysis

- Available Data
  - Dependent Variables:
    - Income per capita in the years 1, 1000, 1500
    - Population density in the years 1, 1000, 1500
  - Main Independent Variables:
    - Technological level in the years 1000 BCE, 1, 1000, 1500

Cross-Country Analysis

- Available Data
  - Dependent Variables:
    - Income per capita in the years 1, 1000, 1500
    - Population density in the years 1, 1000, 1500
  - Main Independent Variables:
    - Technological level in the years 1000 BCE, 1, 1000, 1500
    - Land Productivity

Identification Strategy

- Exploit exogenous sources of cross-country variation in technological level

Identification Strategy

- Exploit exogenous sources of cross-country variation in technological level
  - Historical origins of variation in technological level across countries

Identification Strategy

- Exploit exogenous sources of cross-country variation in technological level
  - Historical origins of variation in technological level across countries
    - Differential onset of the *Neolithic Revolution* across the globe

The Neolithic Revolution

- The transition from hunter-gatherer tribes to agricultural communities

The Neolithic Revolution

- The transition from hunter-gatherer tribes to agricultural communities
  - Emergence of non-food-producing class:

The Neolithic Revolution

- The transition from hunter-gatherer tribes to agricultural communities
  - Emergence of non-food-producing class:
    - $\Longrightarrow$ Knowledge creation (science, technology & written languages)

The Neolithic Revolution

- The transition from hunter-gatherer tribes to agricultural communities
  - Emergence of non-food-producing class:
    - $\Longrightarrow$ Knowledge creation (science, technology & written languages)
    - $\Longrightarrow$ Technological head start

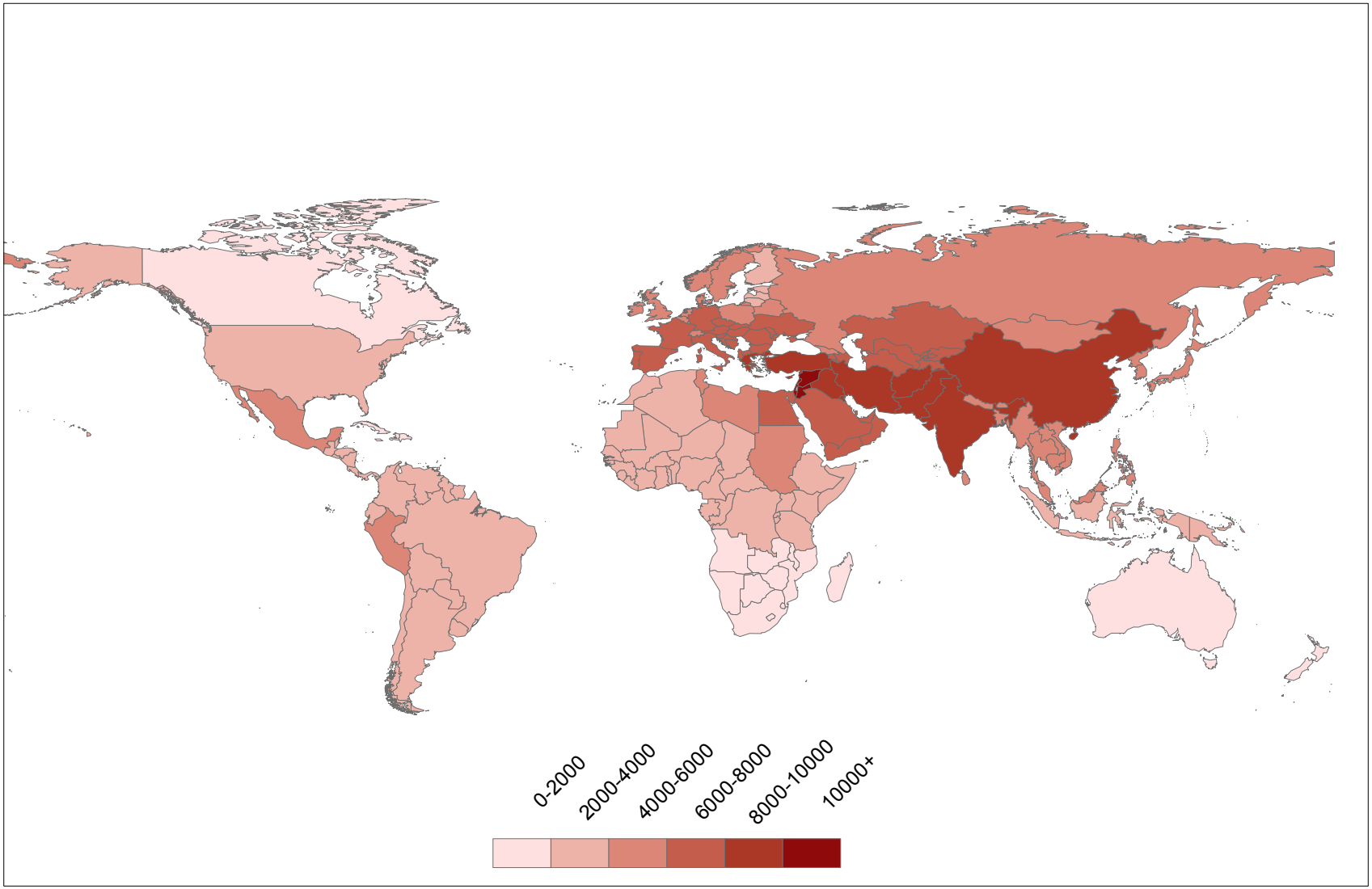
The Neolithic Revolution

- The transition from hunter-gatherer tribes to agricultural communities
  - Emergence of non-food-producing class:
    - $\Longrightarrow$ Knowledge creation (science, technology & written languages)
    - $\Longrightarrow$ Technological head start
- Variations in the timing of the NR:

The Neolithic Revolution

- The transition from hunter-gatherer tribes to agricultural communities
  - Emergence of non-food-producing class:
    - $\Longrightarrow$ Knowledge creation (science, technology & written languages)
    - $\Longrightarrow$ Technological head start
- Variations in the timing of the NR:
  - $\Longrightarrow$ Origins of variations in the level of technology across the globe

Variation in the Onset of the Neolithic Revolution



Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors conducive for biodiversity (climate, latitude, landmass)

Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors conducive for biodiversity (climate, latitude, landmass)
  - Availability of domesticable species of plants and animals

Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors conducive for biodiversity (climate, latitude, landmass)
  - Availability of domesticable species of plants and animals
    - $\Longrightarrow$ Onset of domestication

Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors conducive for biodiversity (climate, latitude, landmass)
  - Availability of domesticable species of plants and animals
    - $\Longrightarrow$ Onset of domestication
- Orientation of continents:

Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors conducive for biodiversity (climate, latitude, landmass)
  - Availability of domesticable species of plants and animals
    - $\Longrightarrow$ Onset of domestication
- Orientation of continents:
  - $\Longrightarrow$ Diffusion of agricultural practices along similar latitudes

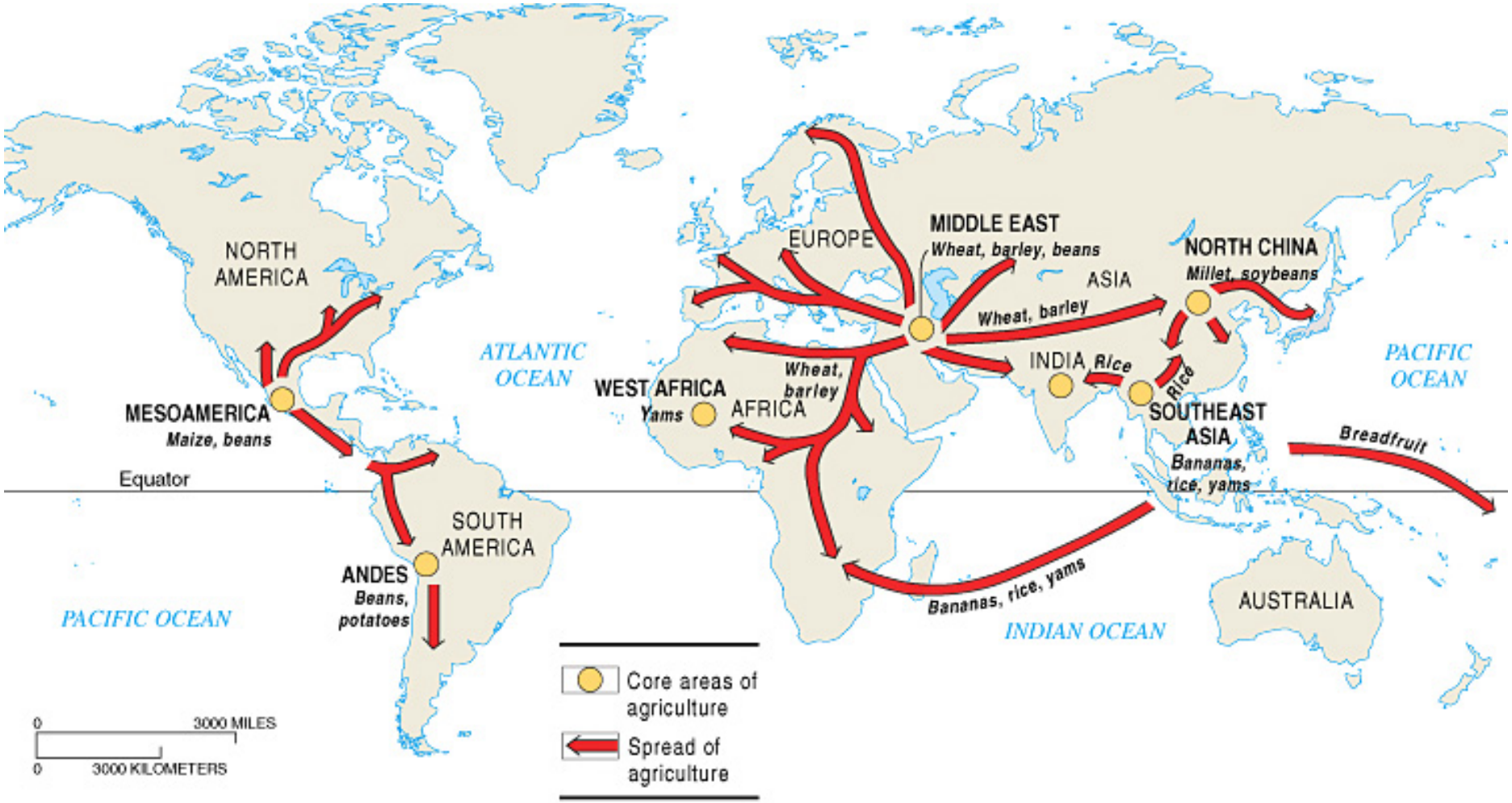
Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors conducive for biodiversity (climate, latitude, landmass)
  - Availability of domesticable species of plants and animals
    - $\Longrightarrow$ Onset of domestication
- Orientation of continents:
  - $\Longrightarrow$ Diffusion of agricultural practices along similar latitudes
- Climatic changes

Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors conducive for biodiversity (climate, latitude, landmass)
  - Availability of domesticable species of plants and animals
    - $\Longrightarrow$ Onset of domestication
- Orientation of continents:
  - $\Longrightarrow$ Diffusion of agricultural practices along similar latitudes
- Climatic changes
  - Hunter-gatherers abandoned their traditional nomadism in order to store food and smooth their consumption (Matranga, 2019)

Spatial Diffusion of the Neolithic Revolution



The Diamond Hypothesis

- The domination of Euro-Asia in the pre-colonial era reflects:

The Diamond Hypothesis

- The domination of Euro-Asia in the pre-colonial era reflects:
  - Larger number of domesticable species of plants and animals

The Diamond Hypothesis

- The domination of Euro-Asia in the pre-colonial era reflects:
  - Larger number of domesticable species of plants and animals
  - East-West orientation

The Diamond Hypothesis

- The domination of Euro-Asia in the pre-colonial era reflects:
  - Larger number of domesticable species of plants and animals
  - East-West orientation
    - $\Longrightarrow$ Technological head start and its effect on development

The Diamond Hypothesis

- The domination of Euro-Asia in the pre-colonial era reflects:
  - Larger number of domesticable species of plants and animals
  - East-West orientation
    - $\Longrightarrow$ Technological head start and its effect on development
- Earlier onset of the Neolithic Revolution:

The Diamond Hypothesis

- The domination of Euro-Asia in the pre-colonial era reflects:
  - Larger number of domesticable species of plants and animals
  - East-West orientation
    - $\Longrightarrow$ Technological head start and its effect on development
- Earlier onset of the Neolithic Revolution:
  - Technological superiority

The Malthusian Hypothesis - Identification Strategy

- Avoiding reverse causality:

The Malthusian Hypothesis - Identification Strategy

- Avoiding reverse causality:
  - Exploit the projected level of technology in each country (rather than the actual one) based on:

The Malthusian Hypothesis - Identification Strategy

- Avoiding reverse causality:
  - Exploit the projected level of technology in each country (rather than the actual one) based on:
    - The time elapsed since the Neolithic Revolution (NR)

The Malthusian Hypothesis - Identification Strategy

- Avoiding reverse causality:
  - Exploit the projected level of technology in each country (rather than the actual one) based on:
    - The time elapsed since the Neolithic Revolution (NR)
- Mitigating concerns about omitted variables (e.g., ability) that could have goverend relationship between [population[& [NR]

The Malthusian Hypothesis - Identification Strategy

- Avoiding reverse causality:
  - Exploit the projected level of technology in each country (rather than the actual one) based on:
    - The time elapsed since the Neolithic Revolution (NR)
- Mitigating concerns about omitted variables (e.g., ability) that could have goverend relationship between [population[& [NR]
  - Instrumental Variable (IV) for the timing of the NR

The Malthusian Hypothesis - Identification Strategy

- Avoiding reverse causality:
  - Exploit the projected level of technology in each country (rather than the actual one) based on:
    - The time elapsed since the Neolithic Revolution (NR)
- Mitigating concerns about omitted variables (e.g., ability) that could have goverend relationship between [population[& [NR]
  - Instrumental Variable (IV) for the timing of the NR
    - Number of prehistoric domesticable species of plants and animals

The Malthusian Hypothesis - Identification Strategy

- Avoiding reverse causality:
  - Exploit the projected level of technology in each country (rather than the actual one) based on:
    - The time elapsed since the Neolithic Revolution (NR)
- Mitigating concerns about omitted variables (e.g., ability) that could have goverend relationship between [population[& [NR]
  - Instrumental Variable (IV) for the timing of the NR
    - Number of prehistoric domesticable species of plants and animals
    - Identifying Assumption: prehistoric domesticable species of plants and animals affected population density only via the NR timing

The Neolithic Revolution & Technological Level: 1000 BCE–1500 CE

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	OLS
	Log Technological Level					
	1000 BCE		1 CE		1500 CE	
Log years since Neolithic	**0.72*** **	**0.47*** **	**0.56*** **	**0.28** **	**0.74*** **	**0.34** **
	(0.06)	(0.12)	(0.06)	(0.12)	(0.06)	(0.10)
Geographical Controls	No	Yes	No	Yes	No	Yes
Continental dummies	No	Yes	No	Yes	No	Yes
Observations	112	112	134	134	134	134
Adjusted R^2	0.51	0.60	0.31	0.63	0.55	0.82

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Empirical Model I

$$\ln P_{i,t} = \alpha_{0,t} + \alpha_{1,t} \ln T_{i,t} + \alpha_{2,t} \ln X_i + \alpha'_{3,t} \Gamma_i + \alpha'_{4,t} D_i + \delta_{i,t}$$

$$\ln y_{i,t} = \beta_{0,t} + \beta_{1,t} \ln T_{i,t} + \beta_{2,t} \ln X_i + \beta'_{3,t} \Gamma_i + \beta'_{4,t} D_i + \varepsilon_{i,t}$$

- $P_{i,t} \equiv$ population density of country i in year t

Empirical Model I

$$\ln P_{i,t} = \alpha_{0,t} + \alpha_{1,t} \ln T_{i,t} + \alpha_{2,t} \ln X_i + \alpha'_{3,t} \Gamma_i + \alpha'_{4,t} D_i + \delta_{i,t}$$

$$\ln y_{i,t} = \beta_{0,t} + \beta_{1,t} \ln T_{i,t} + \beta_{2,t} \ln X_i + \beta'_{3,t} \Gamma_i + \beta'_{4,t} D_i + \varepsilon_{i,t}$$

- $P_{i,t} \equiv$ population density of country i in year t
- $y_{i,t} \equiv$ income per capita of country i in year t

Empirical Model I

$$\ln P_{i,t} = \alpha_{0,t} + \alpha_{1,t} \ln T_{i,t} + \alpha_{2,t} \ln X_i + \alpha'_{3,t} \Gamma_i + \alpha'_{4,t} D_i + \delta_{i,t}$$

$$\ln y_{i,t} = \beta_{0,t} + \beta_{1,t} \ln T_{i,t} + \beta_{2,t} \ln X_i + \beta'_{3,t} \Gamma_i + \beta'_{4,t} D_i + \varepsilon_{i,t}$$

- $P_{i,t} \equiv$ population density of country i in year t
- $y_{i,t} \equiv$ income per capita of country i in year t
- $T_i \equiv$ years elapsed since the onset of agriculture in country i

Empirical Model I

$$\ln P_{i,t} = \alpha_{0,t} + \alpha_{1,t} \ln T_{i,t} + \alpha_{2,t} \ln X_i + \alpha'_{3,t}\Gamma_i + \alpha'_{4,t} D_i + \delta_{i,t}$$

$$\ln y_{i,t} = \beta_{0,t} + \beta_{1,t} \ln T_{i,t} + \beta_{2,t} \ln X_i + \beta'_{3,t}\Gamma_i + \beta'_{4,t} D_i + \varepsilon_{i,t}$$

- $P_{i,t} \equiv$ population density of country i in year t
- $y_{i,t} \equiv$ income per capita of country i in year t
- $T_i \equiv$ years elapsed since the onset of agriculture in country i
- $X_i \equiv$ measure of land productivity for country i

Empirical Model I

$$\ln P_{i,t} = \alpha_{0,t} + \alpha_{1,t} \ln T_{i,t} + \alpha_{2,t} \ln X_i + \alpha'_{3,t}\Gamma_i + \alpha'_{4,t} D_i + \delta_{i,t}$$

$$\ln y_{i,t} = \beta_{0,t} + \beta_{1,t} \ln T_{i,t} + \beta_{2,t} \ln X_i + \beta'_{3,t}\Gamma_i + \beta'_{4,t} D_i + \varepsilon_{i,t}$$

- $P_{i,t} \equiv$ population density of country i in year t
- $y_{i,t} \equiv$ income per capita of country i in year t
- $T_i \equiv$ years elapsed since the onset of agriculture in country i
- $X_i \equiv$ measure of land productivity for country i
- $\Gamma_i \equiv$ vector of geographical controls for country i

Empirical Model I

$$\ln P_{i,t} = \alpha_{0,t} + \alpha_{1,t} \ln T_{i,t} + \alpha_{2,t} \ln X_i + \alpha'_{3,t}\Gamma_i + \alpha'_{4,t} D_i + \delta_{i,t}$$

$$\ln y_{i,t} = \beta_{0,t} + \beta_{1,t} \ln T_{i,t} + \beta_{2,t} \ln X_i + \beta'_{3,t}\Gamma_i + \beta'_{4,t} D_i + \varepsilon_{i,t}$$

- $P_{i,t} \equiv$ population density of country i in year t
- $y_{i,t} \equiv$ income per capita of country i in year t
- $T_i \equiv$ years elapsed since the onset of agriculture in country i
- $X_i \equiv$ measure of land productivity for country i
- $\Gamma_i \equiv$ vector of geographical controls for country i
- $D_i \equiv$ vector of continental fixed effect in country i

Determinants of Population Density in 1500 CE

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	IV
	Log population density in 1500 CE					
Log years since Neolithic	**0.833*** (0.298)**		**1.025*** (0.223)**	**1.087*** (0.184)**	**1.389*** (0.224)**	**2.077*** (0.391)**
Log land productivity		**0.587*** (0.071)**	**0.641*** (0.059)**	**0.576*** (0.052)**	**0.573*** (0.095)**	**0.571*** (0.082)**
Log absolute latitude		-0.425*** (0.124)	-0.353*** (0.104)	-0.314*** (0.103)	-0.278** (0.131)	-0.248** (0.117)
Distance to nearest coast or river				-0.392*** (0.142)	0.220 (0.346)	0.250 (0.333)
% land within 100 km of coast or river				0.899*** (0.282)	1.185*** (0.377)	1.350*** (0.380)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	147	147	147	147	96	96
R^2	0.40	0.60	0.66	0.73	0.73	0.70
First-stage F-statistic						14.65
Overident. p-value						0.44

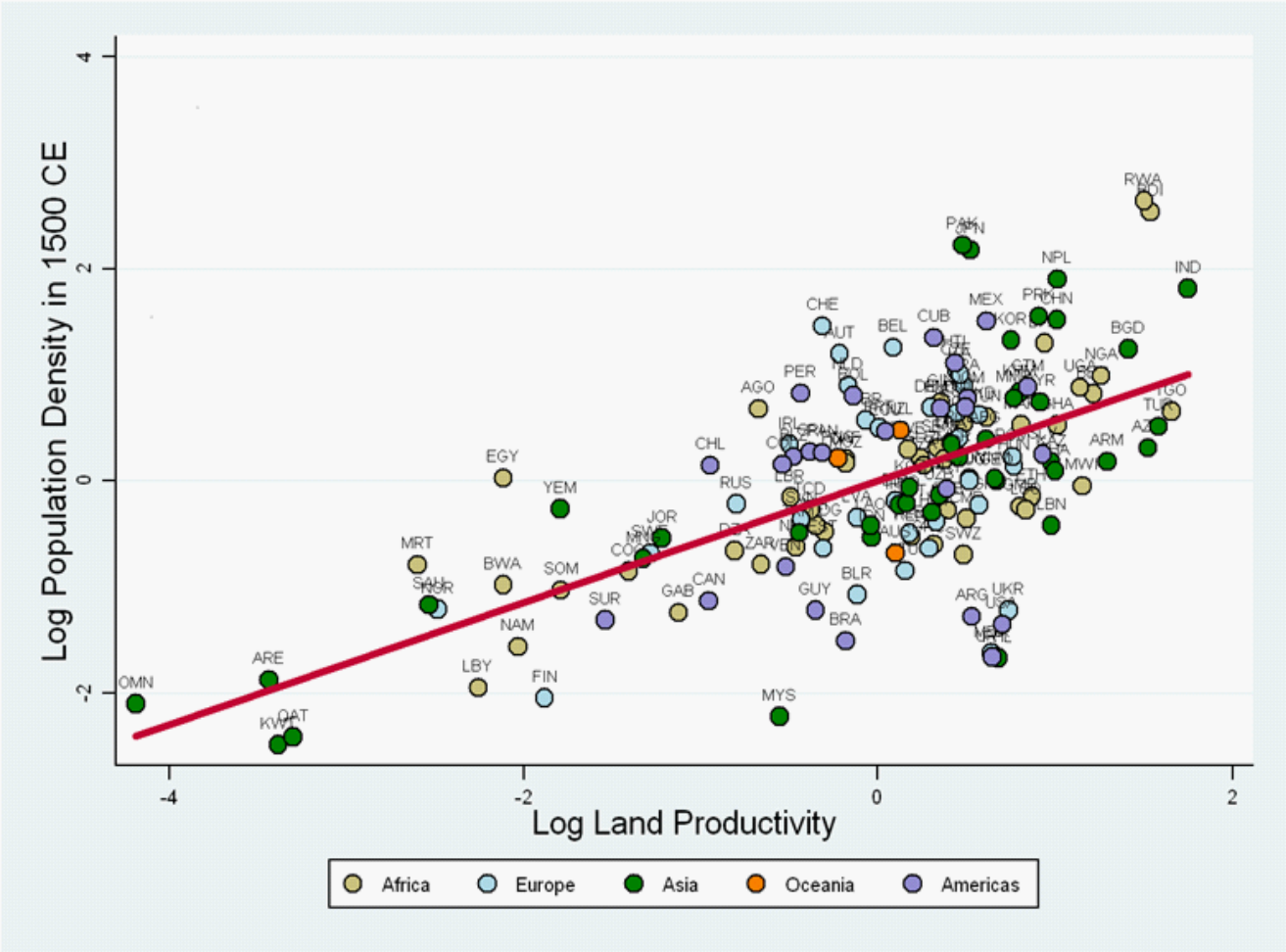
Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Effects on Population Density vs Income per Capita

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	OLS
	Log Income Per Capita in			Log Population Density in		
	1500 CE	1000 CE	1 CE	1500 CE	1000 CE	1 CE
Log years since Neolithic	**0.159**	**0.073**	**0.109**	**1.337****	**0.832****	**1.006****
	(0.136)	(0.045)	(0.072)	(0.594)	(0.363)	(0.483)
Log land productivity	**0.041**	**-0.021**	**-0.001**	**0.584*****	**0.364*****	**0.681****
	(0.025)	(0.025)	(0.027)	(0.159)	(0.110)	(0.255)
Log absolute latitude	-0.041	0.060	-0.175	0.050	-2.140**	-2.163**
	(0.073)	(0.147)	(0.175)	(0.463)	(0.801)	(0.979)
Distance to nearest coast or river	0.215	-0.111	0.043	-0.429	-0.237	0.118
	(0.198)	(0.138)	(0.159)	(1.237)	(0.751)	(0.883)
% land within 100 km of coast or river	0.124	-0.150	0.042	1.855**	1.326**	0.228
	(0.145)	(0.121)	(0.127)	(0.820)	(0.615)	(0.919)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	31	26	29	31	26	29
R^2	0.66	0.68	0.33	0.88	0.95	0.89

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

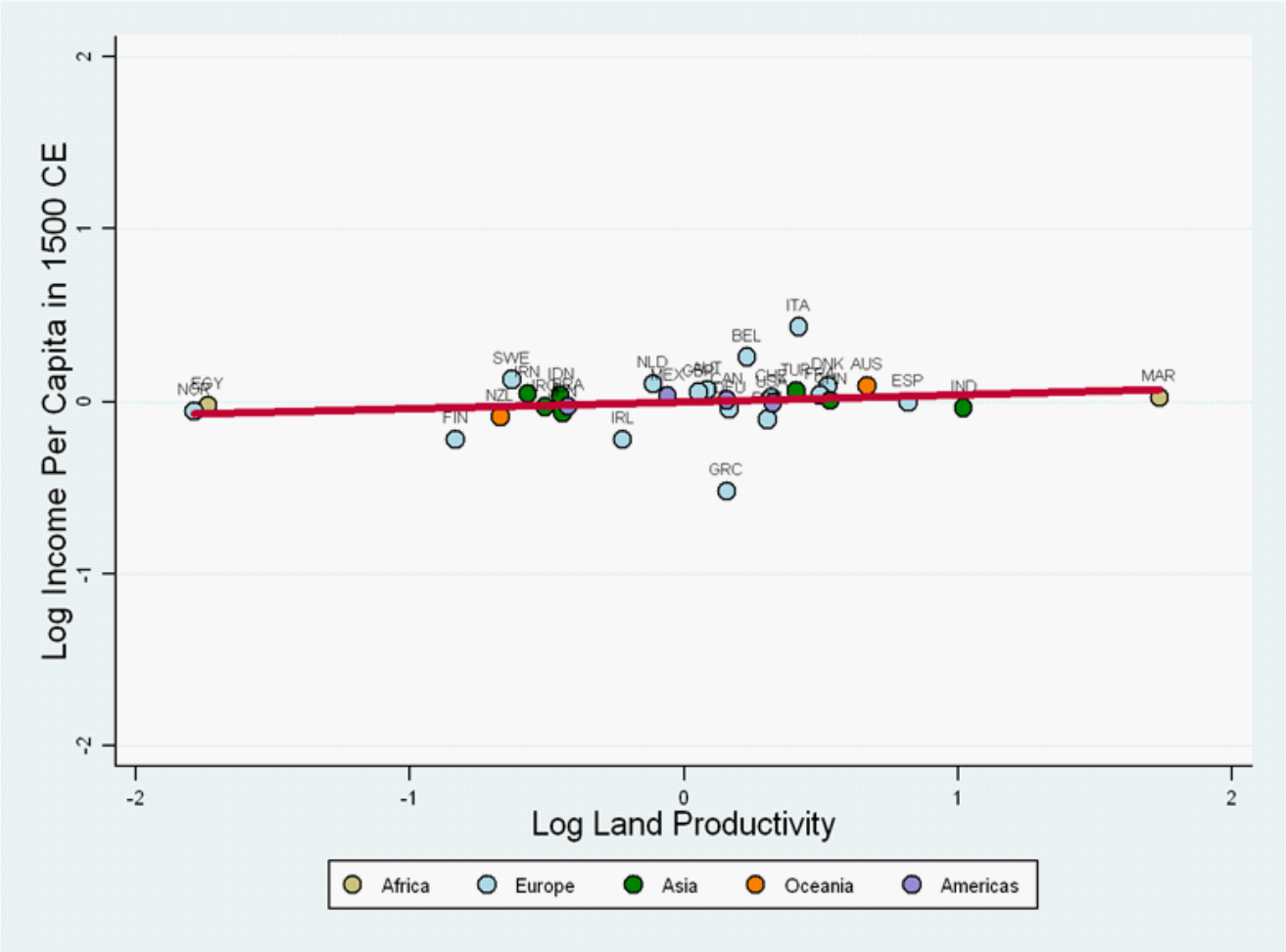
Land Productivity and Population Density in 1500



Conditional on transition timing, geographical factors, and continental fixed effects.

Source: Ashraf-Galor (AER 2011)

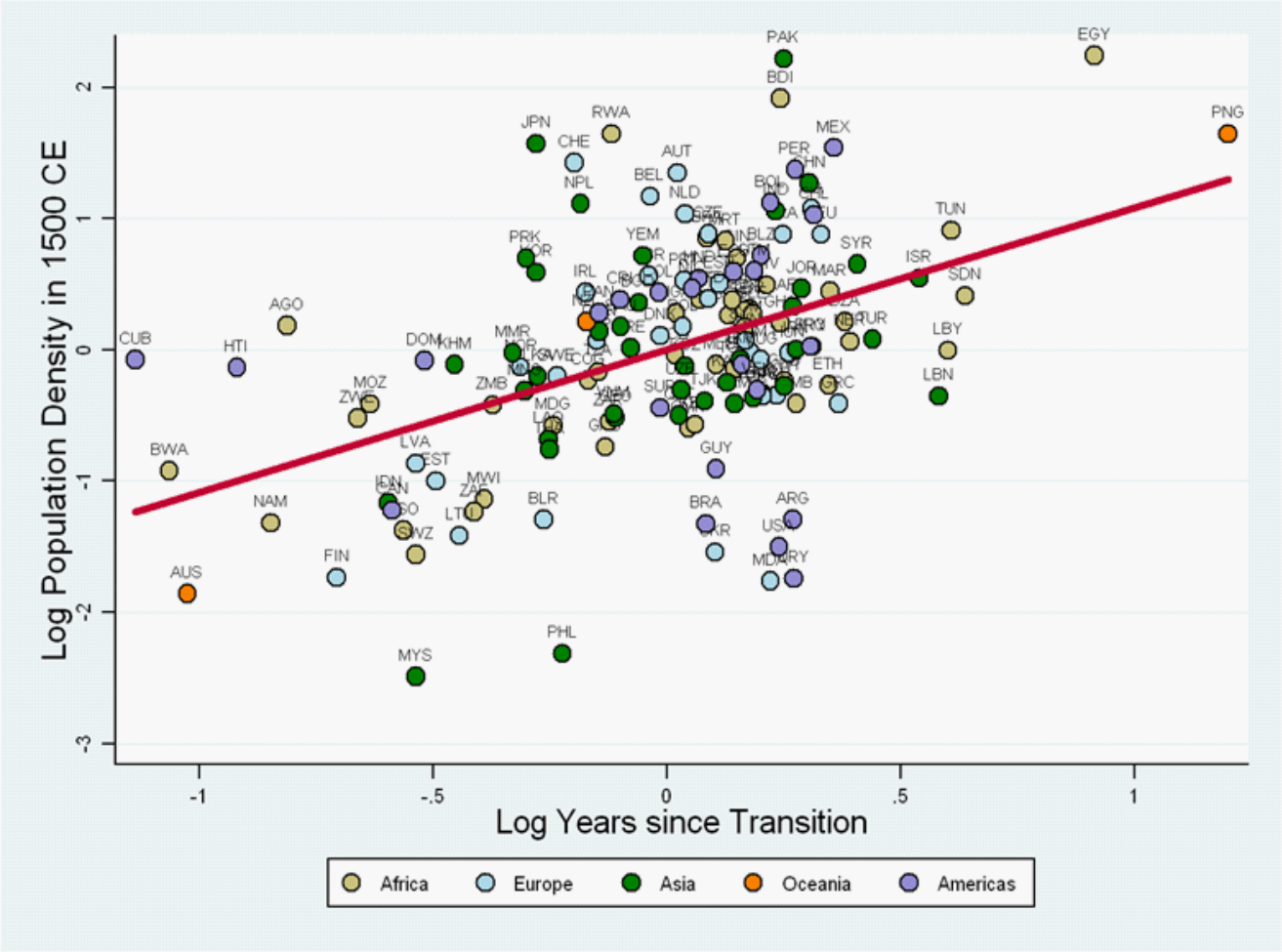
Land Productivity and Income per Capita in 1500



Conditional on transition timing, geographical factors, and continental fixed effects.

Source: Ashraf-Galor (AER 2011)

Technology and Population Density in 1500

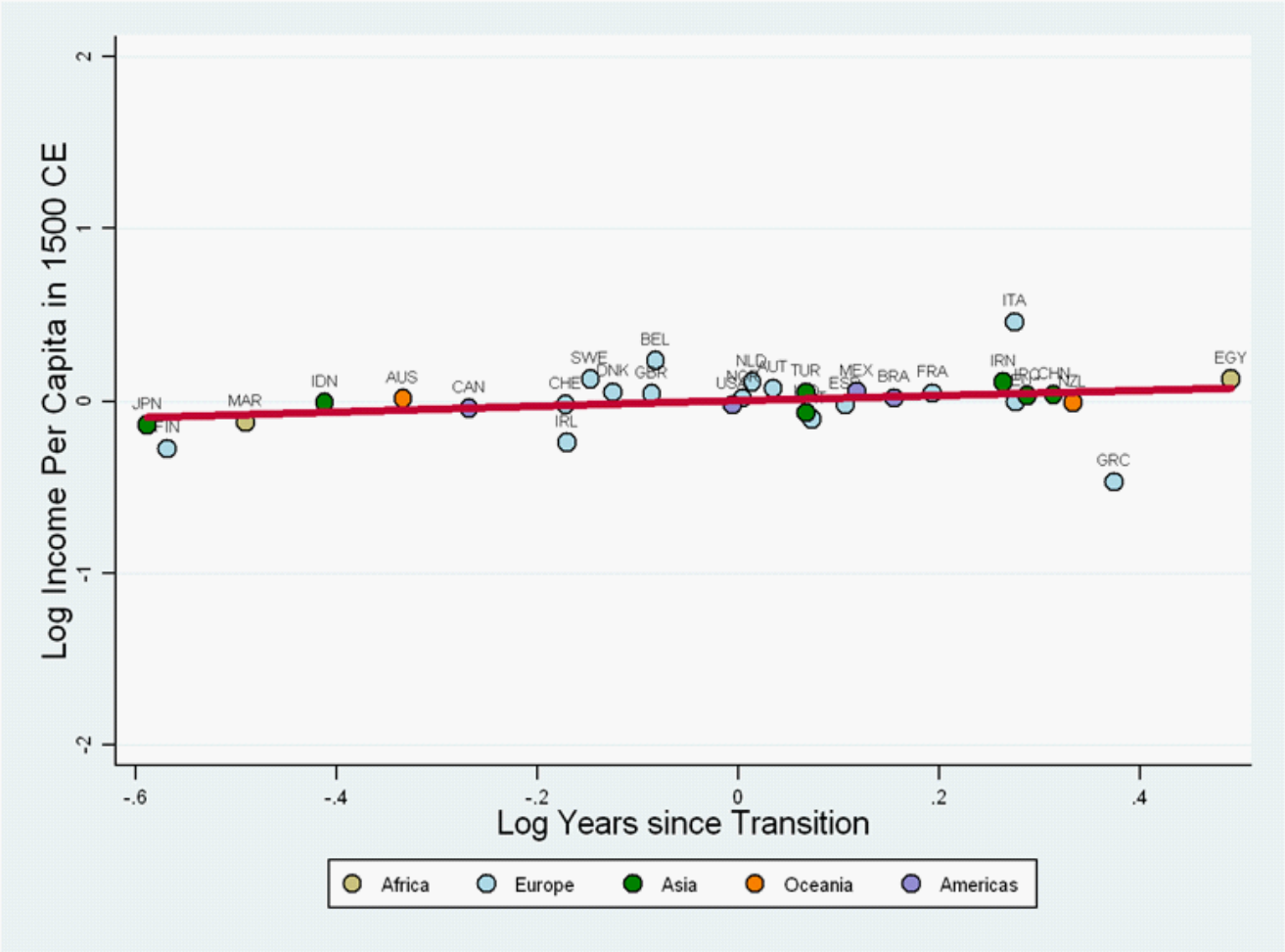


Years elapsed since the Neolithic Transition reflects the technological level in 1500.

Conditional on land productivity, geographical factors, and continental fixed effects.

Source: Ashraf-Galor (AER 2011)

Technology and Income per Capita in 1500



Years elapsed since the Neolithic Transition reflects the technological level in 1500.

Conditional on land productivity, geographical factors, and continental fixed effects.

Source: Ashraf-Galor (AER 2011)

Robustness of Identification Strategy

- Robustness to the inclusion of direct measures of technology

Robustness of Identification Strategy

- Robustness to the inclusion of direct measures of technology
  - Exploit variation in a direct measure of the technology level

Robustness of Identification Strategy

- Robustness to the inclusion of direct measures of technology
  - Exploit variation in a direct measure of the technology level
  - Use prehistoric biogeographic endowments as IV for this measure

Robustness of Identification Strategy

- Robustness to the inclusion of direct measures of technology
  - Exploit variation in a direct measure of the technology level
  - Use prehistoric biogeographic endowments as IV for this measure
- Rubstness to the distance from the technological frontier

Robustness to Direct Measures of Technological Level

	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)
	Log Population Density in:		Log Income Per Capita in:		Log Population Density in:	
	1000 CE	1 CE	1000 CE	1 CE	1000 CE	1 CE
Log Technology Index in Relevant Period	4.315***	4.216***	0.064	0.678	12.762***	7.461**
	(0.850)	(0.745)	(0.230)	(0.432)	(0.918)	(3.181)
Log land productivity	0.449***	0.379***	-0.016	0.004	0.429**	0.725**
	(0.056)	(0.082)	(0.030)	(0.033)	(0.182)	(0.303)
Log absolute latitude	-0.283**	-0.051	0.036	-0.198	-1.919***	-2.350***
	(0.120)	(0.127)	(0.161)	(0.176)	(0.576)	(0.784)
Distance to nearest coast or river	-0.638***	-0.782***	-0.092	0.114	0.609	0.886
	(0.188)	(0.198)	(0.144)	(0.164)	(0.469)	(0.904)
% land within 100 km of coast or river	0.385	0.237	-0.156	0.092	1.265**	0.788
	(0.313)	(0.329)	(0.139)	(0.136)	(0.555)	(0.934)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	140	129	26	29	26	29
R^2	0.61	0.62	0.64	0.30	0.97	0.88

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The Causal Effect of Technological Level on Population Density

	OLS	OLS	IV	OLS	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
	Population Density in:					
	1000CE			1CE		
Log Technology Index in Relevant Period	4.315***	4.198***	14.530***	4.216***	3.947***	10.798***
	(0.850)	(1.164)	(4.437)	(0.745)	(0.983)	(2.857)
Log land productivity	0.449***	0.498***	0.572***	0.379***	0.350**	0.464**
	(0.056)	(0.139)	(0.148)	(0.082)	(0.172)	(0.182)
Log absolute latitude	-0.283**	-0.185	-0.209	-0.051	0.083	-0.052
	(0.120)	(0.151)	(0.209)	(0.127)	(0.170)	(0.214)
Distance to nearest coast or river	-0.638***	-0.363	-1.155*	-0.782***	-0.625	-0.616
	(0.188)	(0.426)	(0.640)	(0.198)	(0.434)	(0.834)
% land within 100 km of coast or river	0.385	0.442	0.153	0.237	0.146	-0.172
	(0.313)	(0.422)	(0.606)	(0.329)	(0.424)	(0.642)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	140	92	92	129	83	83
R^2	0.61	0.55	0.13	0.62	0.58	0.32
First-stage F-statistic			12.52			12.00
Overid. p-value			0.941			0.160

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Robustness to Technology Diffusion and other Geographic Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Population Density in 1500		Log Income Per Capita in 1500		Log Population Density in 1500	
Log Technology Index in Relevant Period	0.828***	0.877***	0.117	0.103	1.498**	1.478**
	(0.208)	(0.214)	(0.221)	(0.214)	(0.546)	(0.556)
Log land productivity	0.559***	0.545***	0.036	0.047	0.596***	0.691***
	(0.048)	(0.063)	(0.032)	(0.037)	(0.123)	(0.122)
Log Distance to Frontier	-0.186***	-0.191***	-0.005	-0.001	-0.130*	-0.108*
	(0.035)	(0.036)	(0.011)	(0.013)	(0.066)	(0.055)
Small Island Dummy	0.067	0.086	-0.118	-0.046	1.962**	2.720***
	(0.582)	(0.626)	(0.216)	(0.198)	(0.709)	(0.699)
Landlocked Dummy	0.131	0.119	0.056	0.024	1.490***	1.269***
	(0.209)	(0.203)	(0.084)	(0.101)	(0.293)	(0.282)
% Land in Temperate Climate Zones		-0.196		-0.192		-1.624*
		(0.513)		(0.180)		(0.917)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	147	147	31	31	31	31
R^2	0.76	0.76	0.67	0.67	0.94	0.96