

# The Malthusian Hypothesis

Ömer Özak

Department of Economics  
Southern Methodist University

Economic Growth and Comparative Development

## Phases of Development: Standard of Living

- The Malthusian Epoch

## Phases of Development: Standard of Living

- The Malthusian Epoch
- The Post-Malthusian Regime

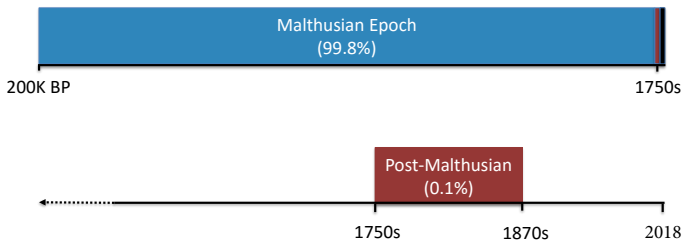
## Phases of Development: Standard of Living

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

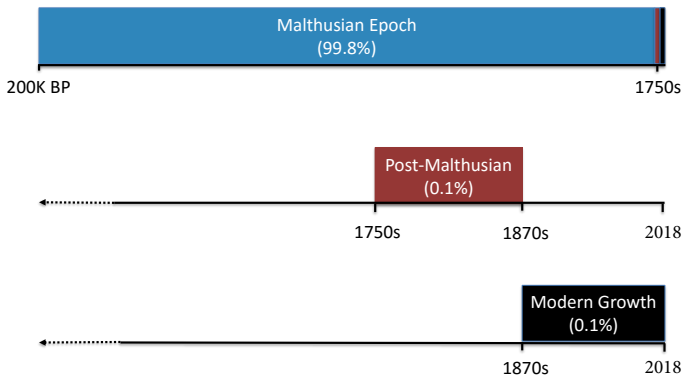
# Phases of Development: Timeline of the Most Developed Economies



# Phases of Development: Timeline of the Most Developed Economies



# Phases of Development: Timeline of the Most Developed Economies



## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth



## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:

## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth

## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)

## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)
- Technological progress over this period

## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)
- Technological progress over this period
  - Increases income per capita in the short-run

## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)
- Technological progress over this period
  - Increases income per capita in the short-run
  - Population adjusts, as long as income remains above subsistence

## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)
- Technological progress over this period
  - Increases income per capita in the short-run
  - Population adjusts, as long as income remains above subsistence
  - Income per capita ultimately returns to its long-run level

## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)
- Technological progress over this period
  - Increases income per capita in the short-run
  - Population adjusts, as long as income remains above subsistence
  - Income per capita ultimately returns to its long-run level
- Technologically advanced & land-rich economies:



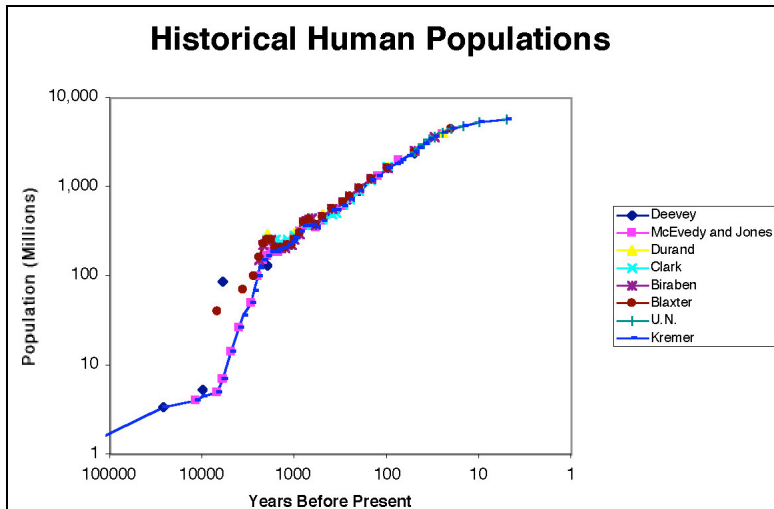
## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)
- Technological progress over this period
  - Increases income per capita in the short-run
  - Population adjusts, as long as income remains above subsistence
  - Income per capita ultimately returns to its long-run level
- Technologically advanced & land-rich economies:
  - Higher population density

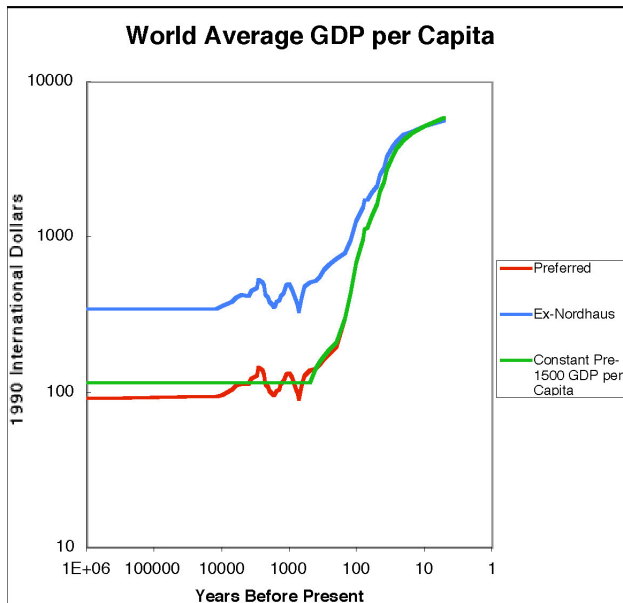
## The Malthusian Epoch

- Characterized by Malthusian dynamics and the absence of economic growth
- Central characteristics of the period:
  - Positive effect of income on population growth
  - Diminishing returns to labor (reflecting the existence of fixed factor)
- Technological progress over this period
  - Increases income per capita in the short-run
  - Population adjusts, as long as income remains above subsistence
  - Income per capita ultimately returns to its long-run level
- Technologically advanced & land-rich economies:
  - Higher population density
  - Similar levels of income per-capita in the long-run

## World Population 100,000 BP–1950CE



## World GDP per capita 100,000 BP–1950CE

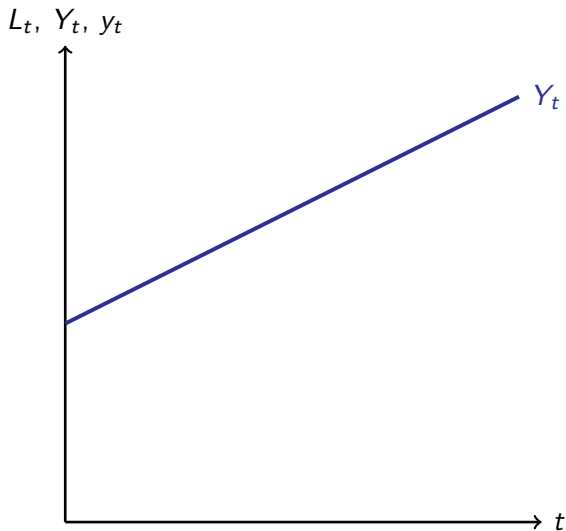


## Malthus' Theory

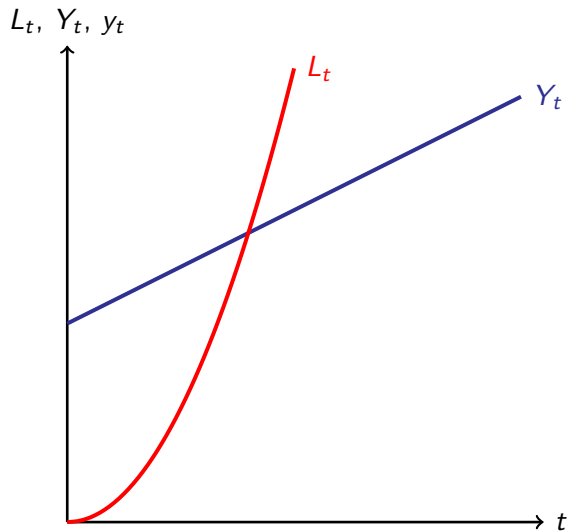
- Population and income growth

*"I think I may make fairly two postulata. First, that food is necessary to the existence of man. Secondly, that the passion between the sexes is necessary and will remain nearly in its present state ... Assuming then my postulata as granted, I say, that the power of population is infinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with numbers will show the immensity of the first power in comparison of the second. By the law of our nature which makes food necessary to the life of man, the effects of these two unequal powers must be kept equal. This implies a strong and constantly operating check on population from the difficulty of subsistence. This difficulty must fall somewhere and must necessarily be severely felt by a large portion of mankind...."*

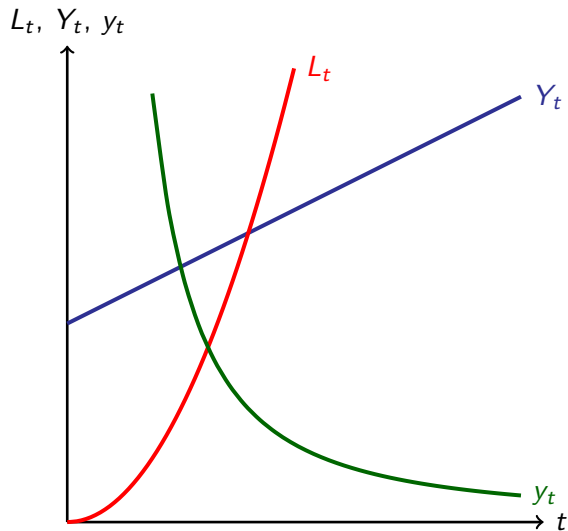
# Population and income growth



## Population and income growth



## Population and income growth



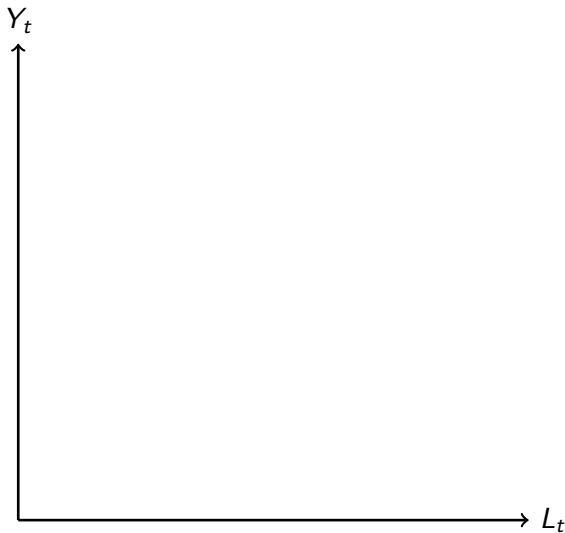


## Malthus' Theory

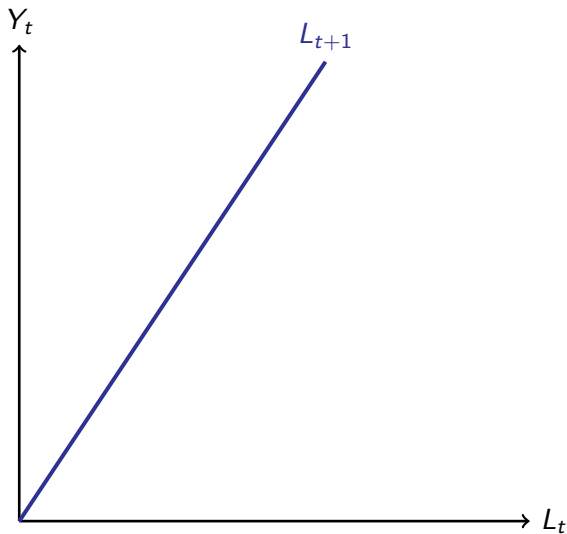
- Population size constrained by resources

*"This natural inequality of the two powers, of population, and of production in the earth, and that great law of our nature which must constantly keep their efforts equal, form the great difficulty that appears to me insurmountable in the way to the perfectibility of society... The checks which repress the superior power of population, and keep its effects on a level with the means of subsistence, are all resolvable into moral restraint, vice and misery.... this constantly subsisting cause of periodical misery has existed ever since we have had any histories of mankind, does exist at present, and will for ever continue to exist, unless some decided change takes place in the physical constitution of our nature."*

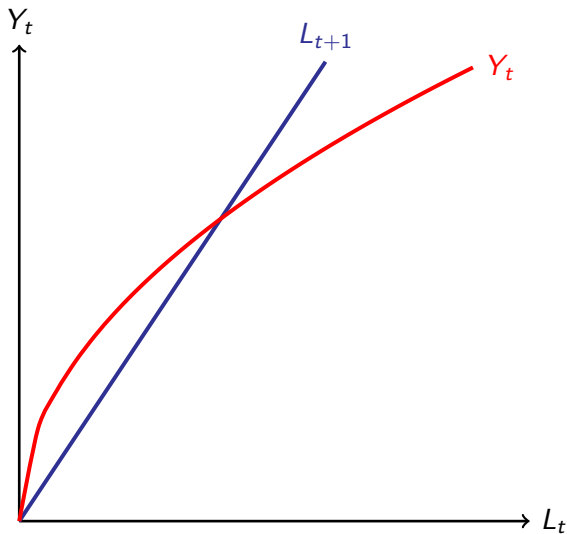
## Population and income



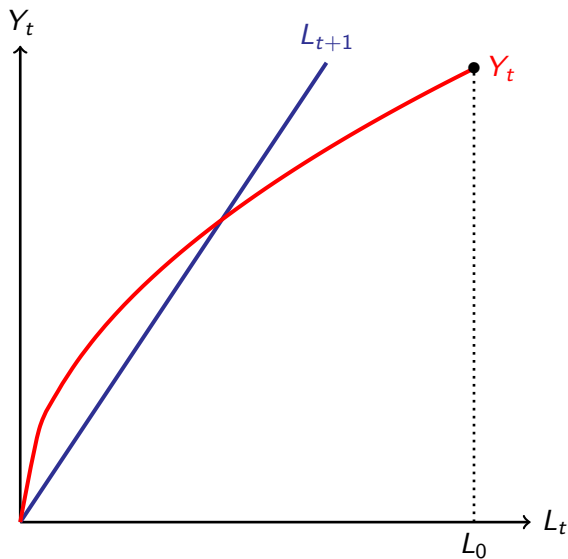
## Population and income



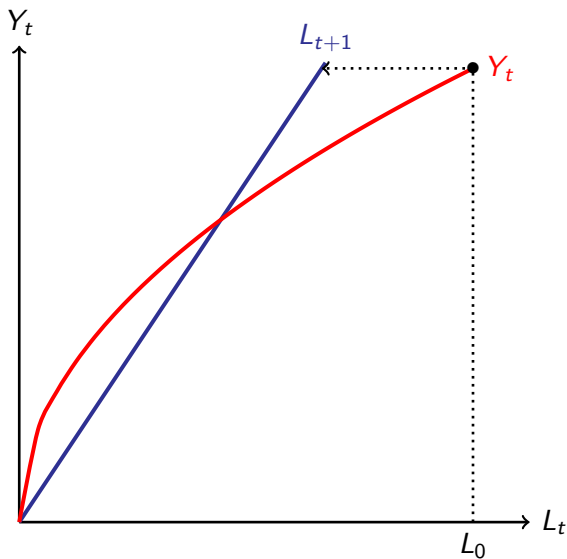
## Population and income



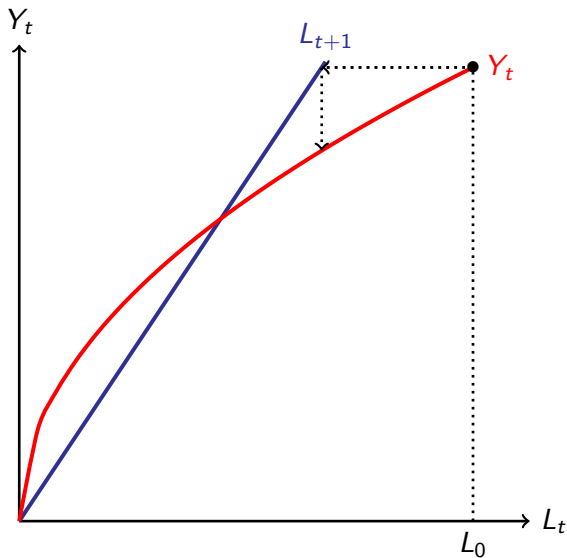
## Population and income



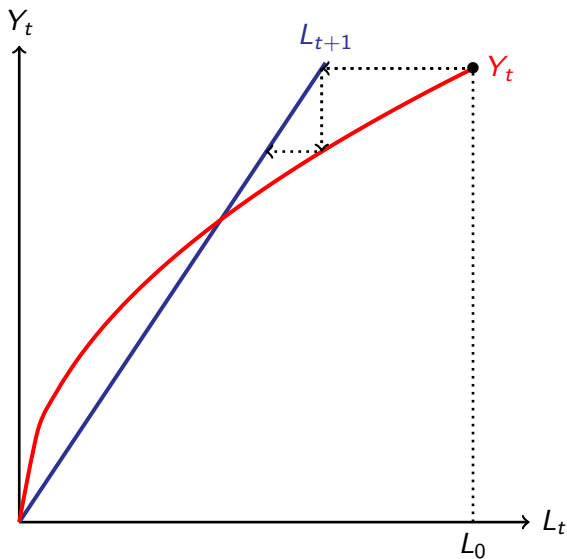
## Population and income



# Population and income

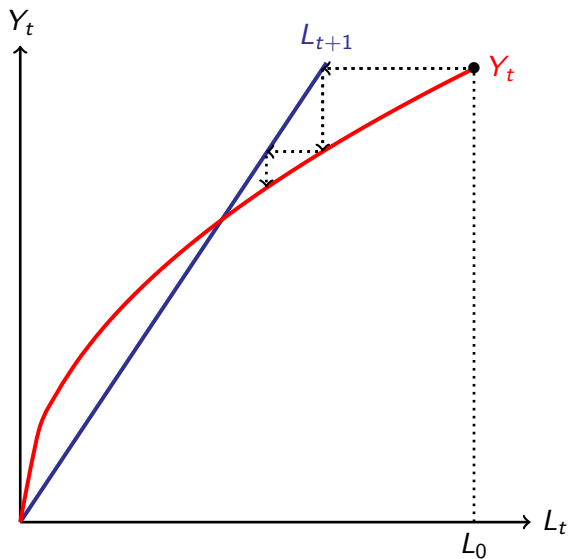


## Population and income

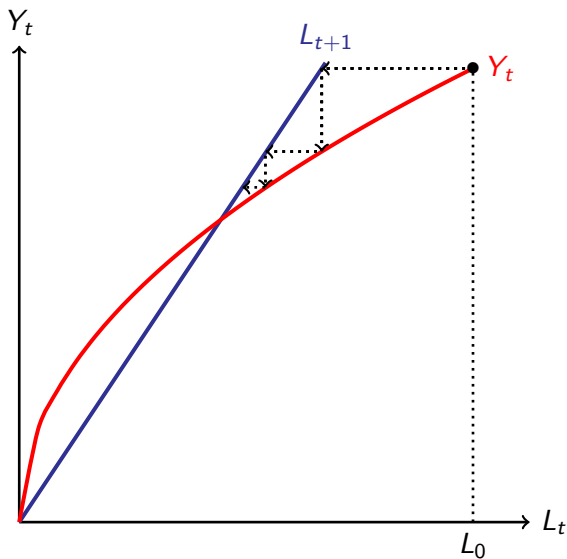




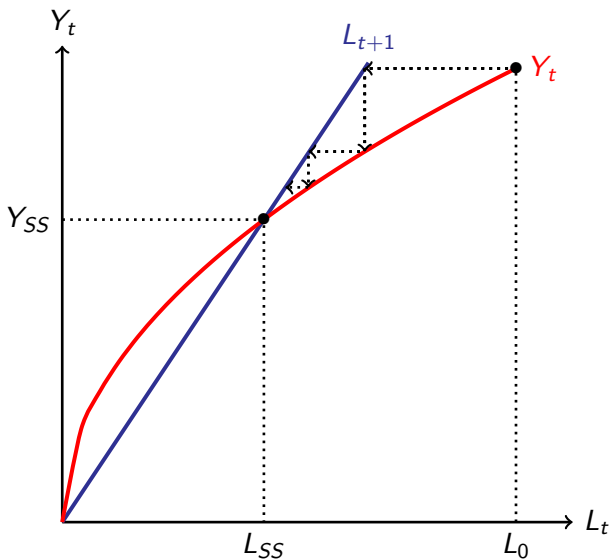
## Population and income



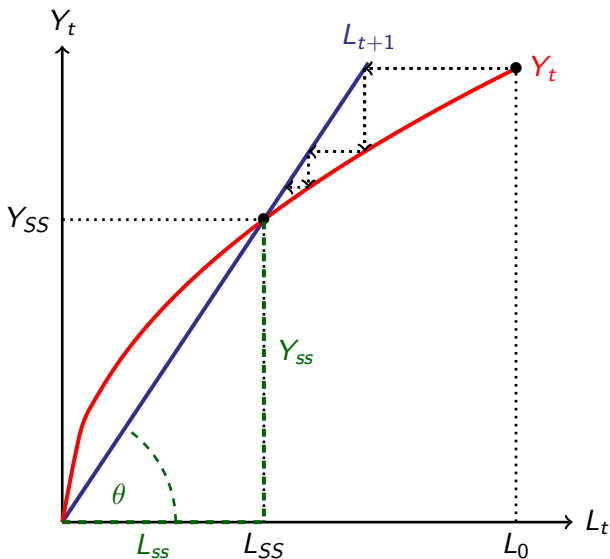
## Population and income



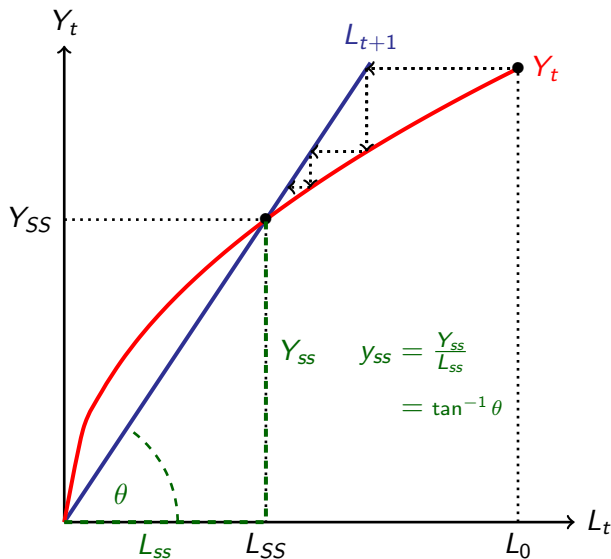
## Population and income



## Population and income



## Population and income



# Malthus' Theory

- Dynamics for Living Creatures

*“Among plants and animals the view of the subject is simple. They are all impelled by a powerful instinct to the increase of their species; and this instinct is interrupted by no reasoning, or doubts about providing for their offspring. Where ever therefore there is liberty, the power of increase is exerted; and the superabundant effects are repressed afterwards by want of room and nourishment, which is common to animals and plants; and among animals, by becoming prey of others”.*

## Example – Rat Attack!

- Mautam (or Mizo)

## Example – Rat Attack!

- Mautam (or Mizo)
  - cyclic ecological phenomenon



## Example – Rat Attack!

- Mautam (or Mizo)
  - cyclic ecological phenomenon
  - occurs every 48 - 50 years

## Example – Rat Attack!

- Mautam (or Mizo)
  - cyclic ecological phenomenon
  - occurs every 48 - 50 years
  - northeastern Indian states of Mizoram and Manipur

## Example – Rat Attack!

- Mautam (or Mizo)
  - cyclic ecological phenomenon
  - occurs every 48 - 50 years
  - northeastern Indian states of Mizoram and Manipur
  - 30% covered by wild bamboo forests

## Example – Rat Attack!

- Mautam (or Mizo)
  - cyclic ecological phenomenon
  - occurs every 48 - 50 years
  - northeastern Indian states of Mizoram and Manipur
  - 30% covered by wild bamboo forests
  - Bamboo trees (*Melocanna baccifera*) flower, generate seeds and die

## Example – Rat Attack!

- Mautam (or Mizo)
  - cyclic ecological phenomenon
  - occurs every 48 - 50 years
  - northeastern Indian states of Mizoram and Manipur
  - 30% covered by wild bamboo forests
  - Bamboo trees (*Melocanna baccifera*) flower, generate seeds and die
  - abundance of seeds ( $> 10$  tons per hectare)

## Example – Rat Attack!

- Mautam (or Mizo)
  - cyclic ecological phenomenon
  - occurs every 48 - 50 years
  - northeastern Indian states of Mizoram and Manipur
  - 30% covered by wild bamboo forests
  - Bamboo trees (*Melocanna baccifera*) flower, generate seeds and die
  - abundance of seeds ( $> 10$  tons per hectare)
  - rat population explosion

## Rat Attack!

Let's see this phenomenon unfold

- Matuam
- How it spreads
- Bamboo explosion
- Reproductive behavior
- Rat explosion

## Malthus' Theory

- Positive checks on population size

*“are extremely various, and include every cause ... which in any degree contributes to shorten the natural duration of human life. Under this head, therefore, may be enumerated all unwholesome occupations, severe labour and exposure to the seasons, extreme poverty, bad nursing of children, great towns, excesses of all kinds, the whole train of common diseases and epidemics, wars, plague, and famine.”*



# Malthus' Theory

- Preventive checks on population size

*"Impelled to the increase of his species by an equally powerful instinct, reason interrupts his career, and asks him whether he may or not bring beings into the world, for whom he cannot provide the means of subsistence. . . . Will he not lower his rank in life? Will he not subject himself to greater difficulties than he at present feels? Will he not be obliged to labour harder? And if he has a large family, will his utmost exertions enable him to support them? May he not see his offspring in rags and misery, and clamoring for bread that he cannot give them?"*

## Human population growth without checks

- Hutterites

## Human population growth without checks

- Hutterites
  - communally oriented Christian sect

## Human population growth without checks

- Hutterites
  - communally oriented Christian sect
  - origins in Switzerland and Bohemia

## Human population growth without checks

- Hutterites
  - communally oriented Christian sect
  - origins in Switzerland and Bohemia
  - women marry young, no birth control

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

16th century  $\approx$  12,000-16,000



## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

16th century  $\approx$  12,000-16,000

19th century  $\approx$  60

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

16th century  $\approx$  12,000-16,000

19th century  $\approx$  60

- full population migrated to US (Dakotas) from Russia in 1872-74

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

16th century  $\approx$  12,000-16,000

19th century  $\approx$  60

- full population migrated to US (Dakotas) from Russia in 1872-74

Population:

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

16th century  $\approx$  12,000-16,000

19th century  $\approx$  60

- full population migrated to US (Dakotas) from Russia in 1872-74

Population:

1880 – 443

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

16th century  $\approx$  12,000-16,000

19th century  $\approx$  60

- full population migrated to US (Dakotas) from Russia in 1872-74

Population:

1880 – 443

1950 – 8,542

## Human population growth without checks

- Hutterites

- communally oriented Christian sect
- origins in Switzerland and Bohemia
- women marry young, no birth control
- subject to religious prosecution (almost exterminated)

Population:

16th century  $\approx$  12,000-16,000

19th century  $\approx$  60

- full population migrated to US (Dakotas) from Russia in 1872-74

Population:

1880 – 443

1950 – 8,542

**4.3% population growth per year!**

## Human population growth without checks

Population	Crude Birth Rate
Hutterites (1948)	45.9
Algeria (Moslems) (1949)	34.1
Jamaica (1948)	30.9
Israel (1948)	26.8
United States (1948)	24.2

Crude Birth Rate: births/1000 people

## Human population growth without checks

Population	Fertility Ratios
Hutterites (1948)	96.3
Algeria (Moslems) (1949)	63.
Jamaica (1948)	49.
Israel (1948)	45.8
United States (1948)	42.3

Fertility Ratio: Children under 5 years of age, per 100 females 15 to 49.



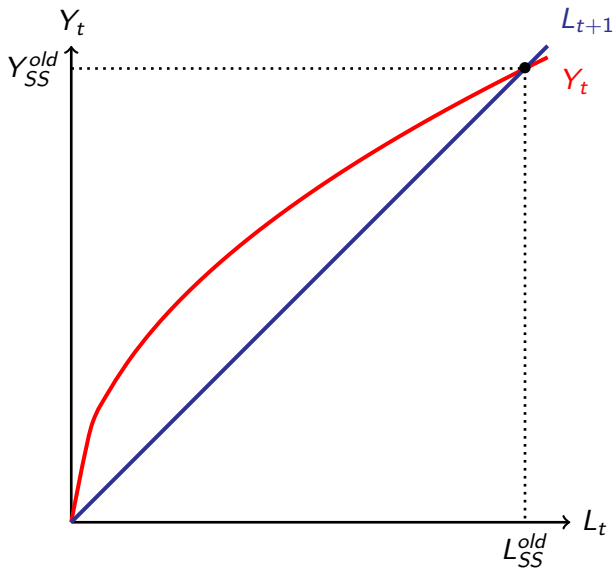
## Population Growth in Humans and Chimpanzees

Population	Type	Total Fertility Rates
<i>Humans</i>		
Hutterites	Agriculturalists	12.4
Ache	Hunter-Gatherer	8.2
Agta	Hunter-Gatherer	6.9
Hadza	Hunter-Gatherer	6.2
Hiwi	Hunter-Gatherer	5.5
Ju/'hoansi	Hunter-Gatherer	4.3
Aborigine	(Acculturated) Hunter-Gatherer	4.3
Gainj	Foragers-Horticulturalists	4.3
Tsimane	Foragers-Horticulturalists	9.2
Yanömamö	Foragers-Horticulturalists	7.9
Herero	Pastoralists	3.3
<i>Wild chimpanzees</i>		
Gombe	East Africa	6.4
Kanyawara	East Africa	7.9
Mahale	East Africa	6.9
Ngogo	East Africa	7.9
Tai	West Africa	7.5

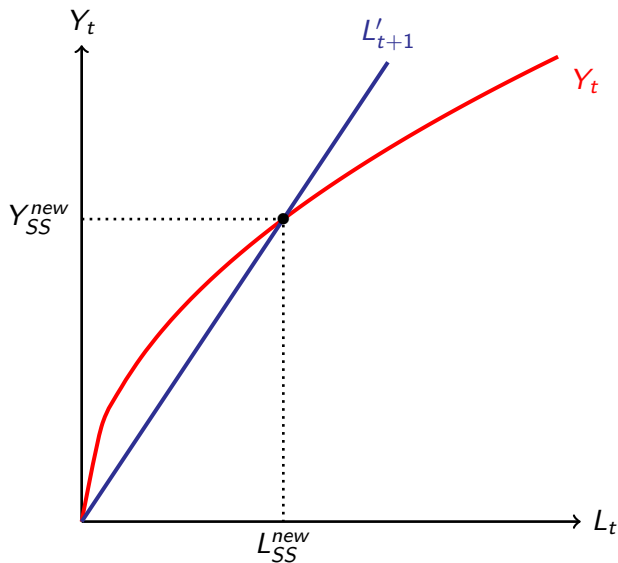
## Human population growth without checks

Initial Population	Growth Rate	Population 1000 Years later	Years to reach 10 billion
1000	0.04	$1e + 19$	411
1000	0.01	20,959,155	1,620
1000	0.001	2717	16,126
1000	0.0001	1105	161,189

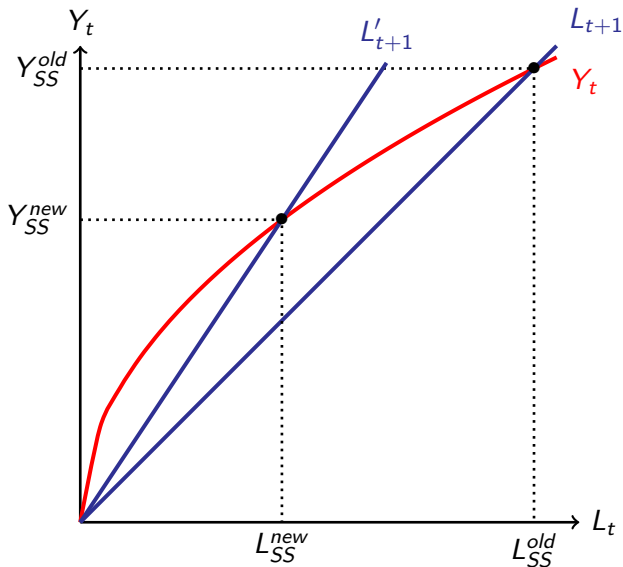
## Effect of positive or preventive checks



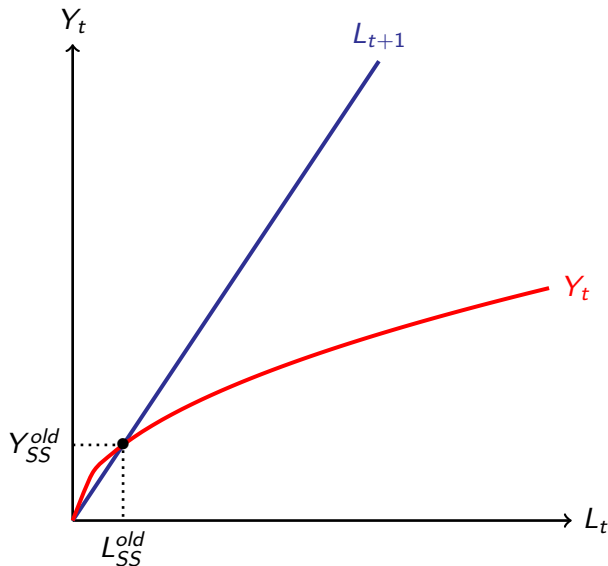
## Effect of positive or preventive checks



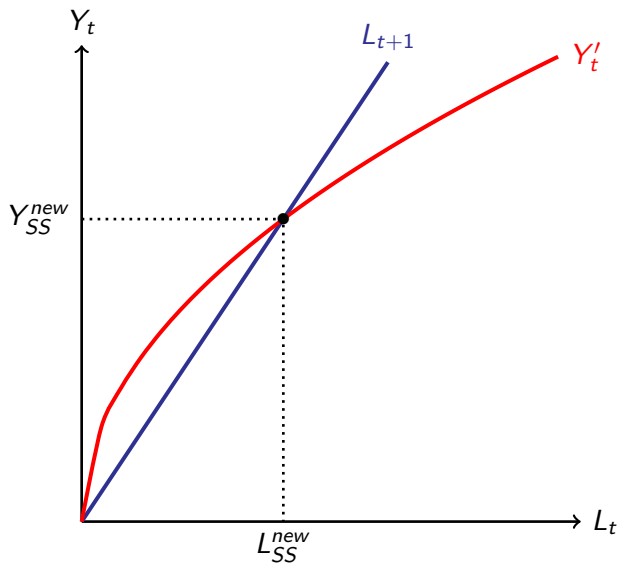
## Effect of positive or preventive checks



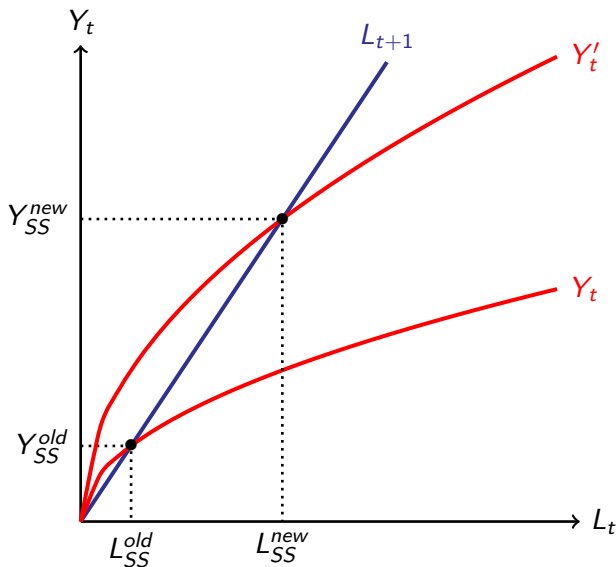
## Effect of better resources



## Effect of better resources



## Effect of better resources





## 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 cultivation of a new world crop – potato

## Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the cultivation of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1800)

## Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the cultivation of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1800)
  - Triggered by superior agricultural technology

## Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the cultivation of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1800)
  - Triggered by superior agricultural technology
- The dynamics of the English economy (1348 - 1700)

## Malthusian Dynamics - Prominent Examples

- The dynamics of Irish economy (1650 - 1850)
  - Triggered by the cultivation of a new world crop – potato
- The dynamics of the Chinese Economy (1500 - 1800)
  - Triggered by superior agricultural technology
- The dynamics of the English economy (1348 - 1700)
  - Triggered by the Black Death

## Malthusian Dynamics - Ireland (1650 - 1850)

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

## Malthusian Dynamics - Ireland (1650 - 1850)

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



## Malthusian Dynamics - Ireland (1650 - 1850)

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

## Malthusian Dynamics - Ireland (1650 - 1850)

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

## Malthusian Dynamics - Ireland (1650 - 1850)

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

## Malthusian Dynamics - Ireland (1650 - 1850)

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

## Malthusian Dynamics - Ireland (1650 - 1850)

- The Colombian Exchange  $\implies$  massive cultivation of potato post-1650
  - 1650-1840s
    - Population increases from 2 to 6 million
    - Income per capita increases only very modestly
  - 1845-1852 Potato blight destroys crops  $\implies$  Great Famine
    - Population decreases by about 2 million
    - (1M Famine death & 1M emigration to the New World)

## Malthusian Dynamics - China (1500 - 1800)

- Superior agricultural technology

## Malthusian Dynamics - China (1500 - 1800)

- Superior agricultural technology
  - 1500-1820

## Malthusian Dynamics - China (1500 - 1800)

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



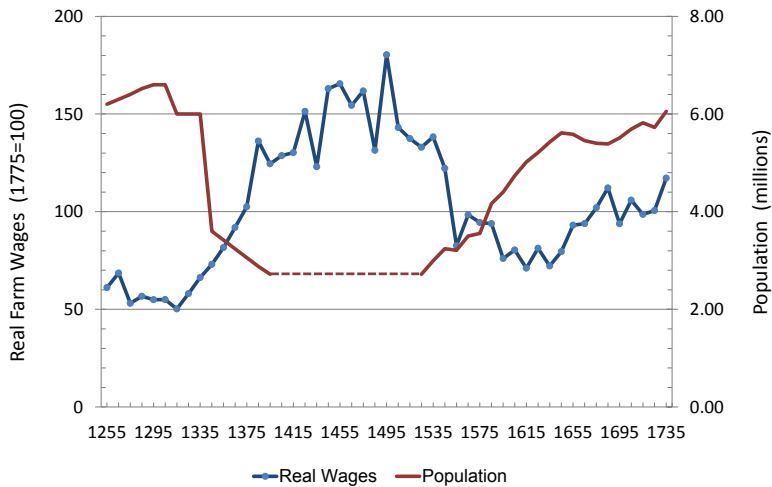
## Malthusian Dynamics - China (1500 - 1800)

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

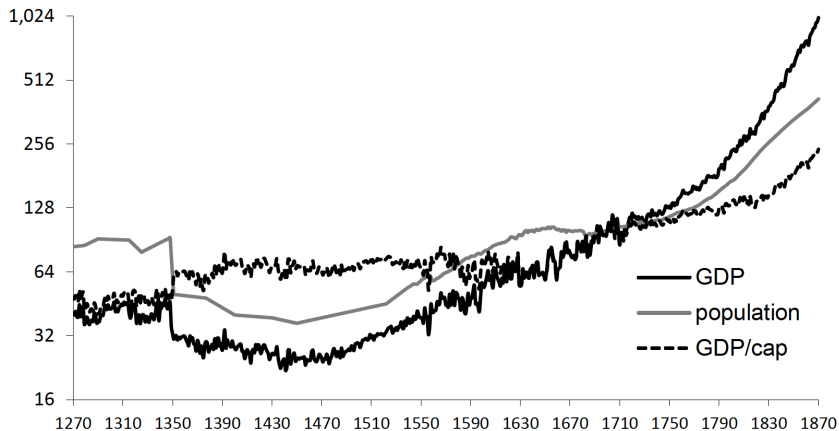
## Malthusian Dynamics - China (1500 - 1800)

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

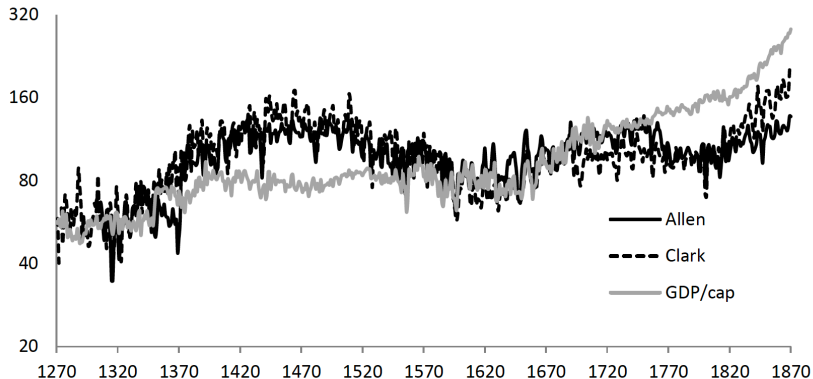
## Malthusian Adjustments to the Black Death: England, 1348–1750CE



# Malthusian Adjustments to the Black Death: England, 1348–1750CE



## Malthusian Adjustments to the Black Death: England, 1348–1750CE



## The Malthus Delusion

- No micro-foundation in human optimizing behavior

## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions

## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions
  - Fertility control
    - e.g. infanticide, abortion, breast-feeding, condoms, age of marriage



## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions
  - Fertility control
    - e.g. infanticide, abortion, breast-feeding, condoms, age of marriage
  - Quantity-quality trade-off (are children a normal good?)

## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions
  - Fertility control
    - e.g. infanticide, abortion, breast-feeding, condoms, age of marriage
  - Quantity-quality trade-off (are children a normal good?)
- Decreasing marginal product of labor?

## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions
  - Fertility control
    - e.g. infanticide, abortion, breast-feeding, condoms, age of marriage
  - Quantity-quality trade-off (are children a normal good?)
- Decreasing marginal product of labor?
  - ⇒ land constraints always binding

## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions
  - Fertility control
    - e.g. infanticide, abortion, breast-feeding, condoms, age of marriage
  - Quantity-quality trade-off (are children a normal good?)
- Decreasing marginal product of labor?
  - ⇒ land constraints always binding
- Demographic shocks are (quasi-)stationary

## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions
  - Fertility control
    - e.g. infanticide, abortion, breast-feeding, condoms, age of marriage
  - Quantity-quality trade-off (are children a normal good?)
- Decreasing marginal product of labor?
  - ⇒ land constraints always binding
- Demographic shocks are (quasi-)stationary
- Income per capita above “subsistence” level

## The Malthus Delusion

- No micro-foundation in human optimizing behavior
  - Humans make directly or indirectly fertility decisions
  - Fertility control
    - e.g. infanticide, abortion, breast-feeding, condoms, age of marriage
  - Quantity-quality trade-off (are children a normal good?)
- Decreasing marginal product of labor?
  - ⇒ land constraints always binding
- Demographic shocks are (quasi-)stationary
- Income per capita above “subsistence” level
- Population size affects technological progress, specialization and economies of scale

## The Malthus Delusion

- New models that incorporate optimal choice and Q-Q trade-offs

## The Malthus Delusion

- New models that incorporate optimal choice and Q-Q trade-offs  
⇒ importance of skill premia in Malthusian era?



## The Malthus Delusion

- New models that incorporate optimal choice and Q-Q trade-offs  
 $\implies$  importance of skill premia in Malthusian era?
- Malthusian model predicts population to be  $I(1)$  and income per capita  $I(0)$  if technology is  $I(1)$ . Seems to hold in data.

## The Malthus Delusion

- New models that incorporate optimal choice and Q-Q trade-offs  
⇒ importance of skill premia in Malthusian era?
- Malthusian model predicts population to be  $I(1)$  and income per capita  $I(0)$  if technology is  $I(1)$ . Seems to hold in data.  
⇒ still more data and analysis required...regional, non-European, pre-1000CE

## The Malthus Delusion

- New models that incorporate optimal choice and Q-Q trade-offs  
⇒ importance of skill premia in Malthusian era?
- Malthusian model predicts population to be  $I(1)$  and income per capita  $I(0)$  if technology is  $I(1)$ . Seems to hold in data.  
⇒ still more data and analysis required...regional, non-European, pre-1000CE
- Main prediction is income per capita constant

## The Malthus Delusion

- New models that incorporate optimal choice and Q-Q trade-offs  
⇒ importance of skill premia in Malthusian era?
- Malthusian model predicts population to be  $I(1)$  and income per capita  $I(0)$  if technology is  $I(1)$ . Seems to hold in data.  
⇒ still more data and analysis required...regional, non-European, pre-1000CE
- Main prediction is income per capita constant  
⇒ level not really important (of course “subsistence” is lower bound)

## Central Elements

- Positive effect of income on population

## Central Elements

- Positive effect of income on population
  - $y \uparrow$

## Central Elements

- Positive effect of income on population
  - $y \uparrow$

## Central Elements

- Positive effect of income on population
  - $y \uparrow \Rightarrow L \uparrow$



## Central Elements

- Positive effect of income on population
  - $y \uparrow \implies L \uparrow$
- Fixed factor of production - Land

## Central Elements

- Positive effect of income on population
  - $y \uparrow \Rightarrow L \uparrow$
- Fixed factor of production - Land
  - $L \uparrow$

## Central Elements

- Positive effect of income on population
  - $y \uparrow \Rightarrow L \uparrow$
- Fixed factor of production - Land
  - $L \uparrow$

## Central Elements

- Positive effect of income on population

- $y \uparrow \implies L \uparrow$

- Fixed factor of production - Land

- $L \uparrow \implies AP_L \downarrow$

## Central Elements

- Positive effect of income on population

- $y \uparrow \implies L \uparrow$

- Fixed factor of production - Land

- $L \uparrow \implies AP_L \downarrow \implies y \downarrow$

## The Basic Structure of the Model

- Overlapping-generations economy

## The Basic Structure of the Model

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

## The Basic Structure of the Model

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



## The Basic Structure of the Model

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

## The Basic Structure of the Model

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

## The Basic Structure of the Model

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

## Production

- The output produced in period  $t$

$$Y_t =$$

## Production

- The output produced in period  $t$

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

## Production

- The output produced in period  $t$

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

- $L_t \equiv$  labor employed in period  $t$

## Production

- The output produced in period  $t$

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

- $L_t \equiv$  labor employed in period  $t$
- $X \equiv$  land

## Production

- The output produced in period  $t$

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

- $L_t \equiv$  labor employed in period  $t$
- $X \equiv$  land
- $A \equiv$  technological level



## Production

- The output produced in period  $t$

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

- $L_t \equiv$  labor employed in period  $t$
- $X \equiv$  land
- $A \equiv$  technological level
- $AX \equiv$  effective resources

## Production

- The output produced in period  $t$

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

- $L_t \equiv$  labor employed 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  $t$

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

- $L_t \equiv$  labor employed 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  $t$

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

- $L_t \equiv$  labor employed 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  $t$

$$u_t = (n_t)^\gamma (c_t)^{1-\gamma} \quad 0 < \gamma < 1$$

## Preferences and Budget Constraint

- Preferences of an adult at time  $t$

$$u_t = (n_t)^\gamma (c_t)^{1-\gamma} \quad 0 < \gamma < 1$$

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

## Preferences and Budget Constraint

- Preferences of an adult at time  $t$

$$u_t = (n_t)^\gamma (c_t)^{1-\gamma} \quad 0 < \gamma < 1$$

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

## Preferences and Budget Constraint

- Preferences of an adult at time  $t$

$$u_t = (n_t)^\gamma (c_t)^{1-\gamma} \quad 0 < \gamma < 1$$

- $n_t \equiv$  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  $t$

$$u_t = (n_t)^\gamma (c_t)^{1-\gamma} \quad 0 < \gamma < 1$$

- $n_t \equiv$  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  $t$

$$u_t = (n_t)^\gamma (c_t)^{1-\gamma} \quad 0 < \gamma < 1$$

- $n_t \equiv$  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

$$c_t =$$



## 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

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

$$\rho n_t = \gamma y_t$$

- Optimal number of children

## Optimization

- Optimal expenditure on consumption and children

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

$$\rho n_t = \gamma y_t$$

- Optimal number of children

$$n_t =$$

## Optimization

- Optimal expenditure on consumption and children

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

$$\rho n_t = \gamma y_t$$

- Optimal number of children

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



## Optimization

- Optimal expenditure on consumption and children

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

$$\rho n_t = \gamma y_t$$

- Optimal number of children

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

## Optimization

- Optimal expenditure on consumption and children

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

$$\rho n_t = \gamma y_t$$

- Optimal number of children

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

## Optimization

- Optimal expenditure on consumption and children

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

$$\rho n_t = \gamma y_t$$

- Optimal number of children

$$n_t = \frac{\gamma}{\rho} y_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

## Optimization

- Optimal expenditure on consumption and children

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

$$\rho n_t = \gamma y_t$$

- Optimal number of children

$$n_t = \frac{\gamma}{\rho} y_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Since  $y_t = (AX/L_t)^\alpha$

## 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

$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

## Population Dynamics

- The evolution of the size of the working population

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

where

$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Population dynamics:

$$L_{t+1} =$$

## Population Dynamics

- The evolution of the size of the working population

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

where

$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Population dynamics:

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

## Population Dynamics

- The evolution of the size of the working population

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

where

$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Population dynamics:

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

## Population Dynamics

- The evolution of the size of the working population

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

where

$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Population dynamics:

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

## Population Dynamics

- The evolution of the size of the working population

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

where

$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Population dynamics:

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

## Population Dynamics

- The evolution of the size of the working population

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

where

$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Population dynamics:

$$L_{t+1} = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha L_t = \frac{\gamma}{\rho} (AX)^\alpha L_t^{1-\alpha}$$

## Population Dynamics

- The evolution of the size of the working population

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

where

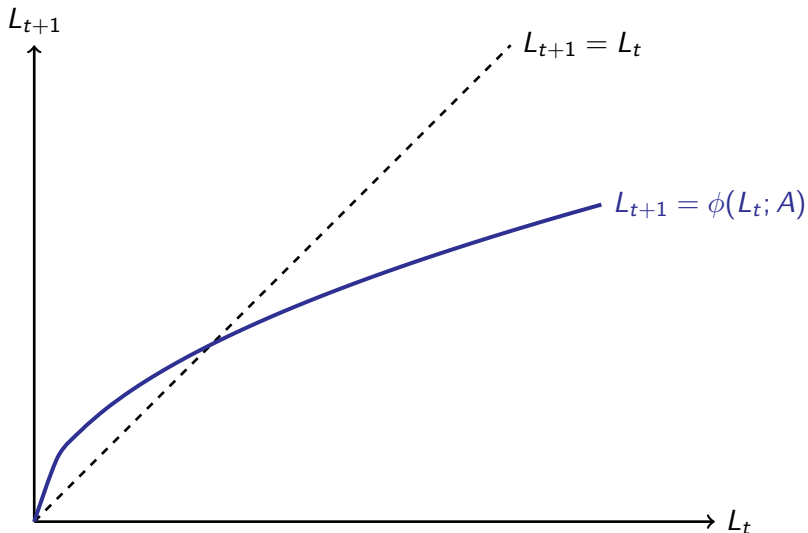
$$n_t = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha$$

- Population dynamics:

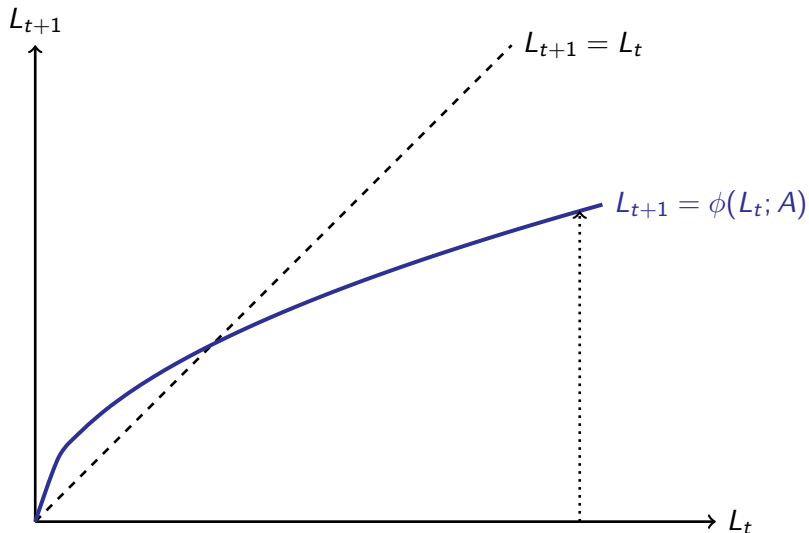
$$L_{t+1} = \frac{\gamma}{\rho} \left[ \frac{AX}{L_t} \right]^\alpha L_t = \frac{\gamma}{\rho} (AX)^\alpha L_t^{1-\alpha} \equiv \phi(L_t; A)$$



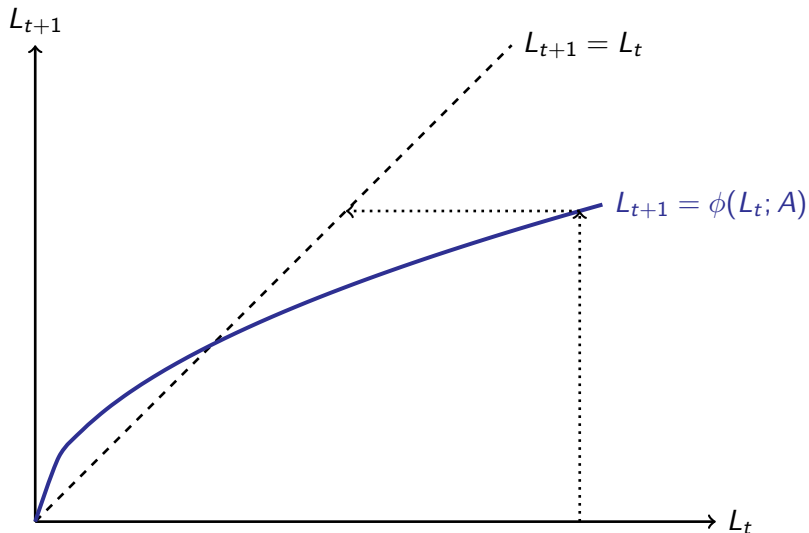
# Population Dynamics



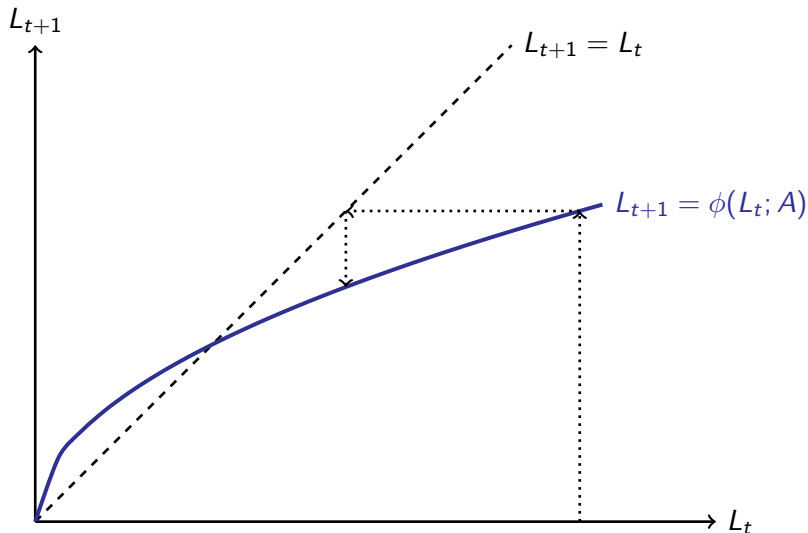
## Population Dynamics



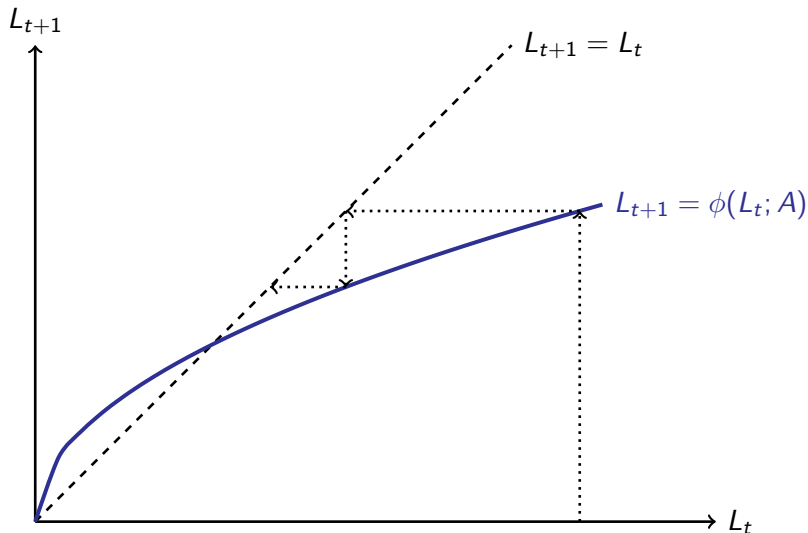
## Population Dynamics



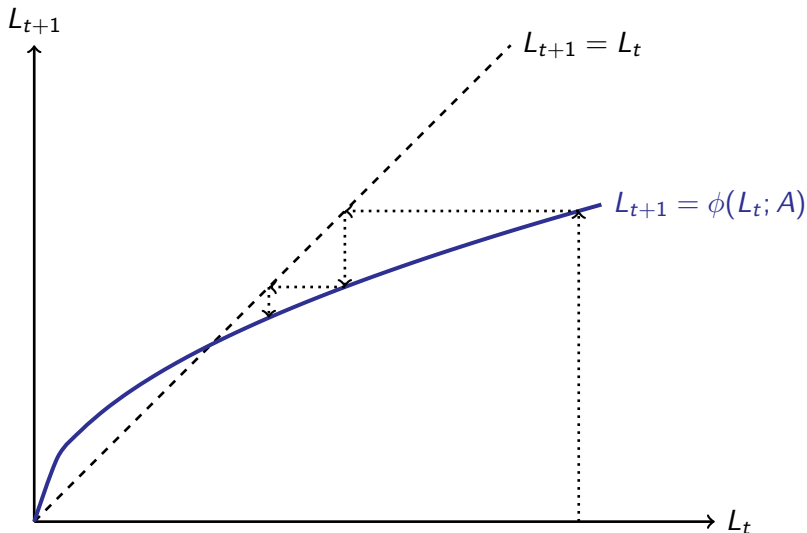
## Population Dynamics



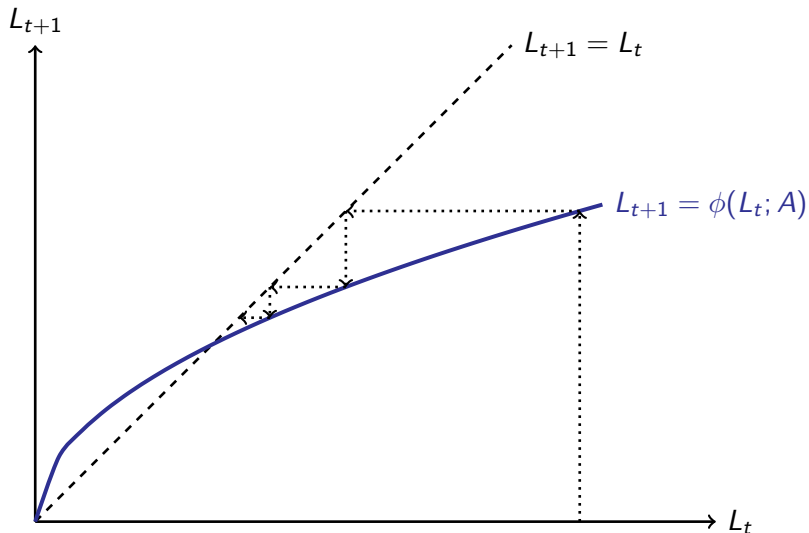
## Population Dynamics



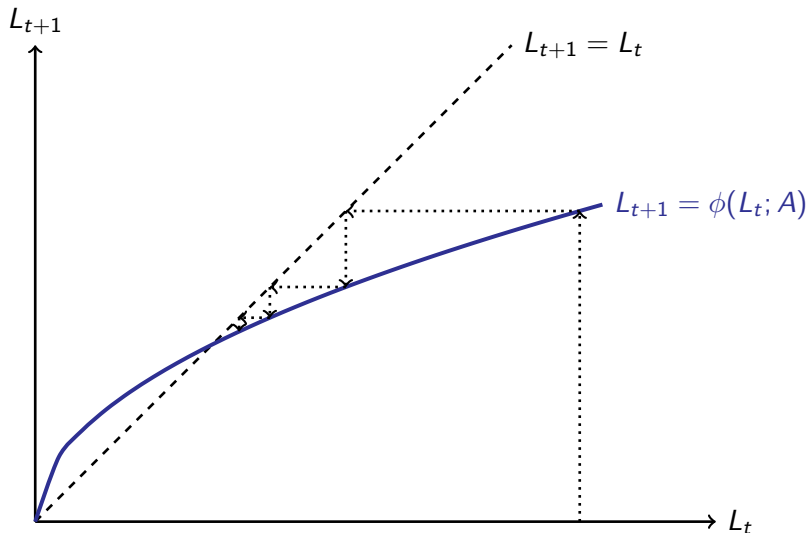
## Population Dynamics



## Population Dynamics

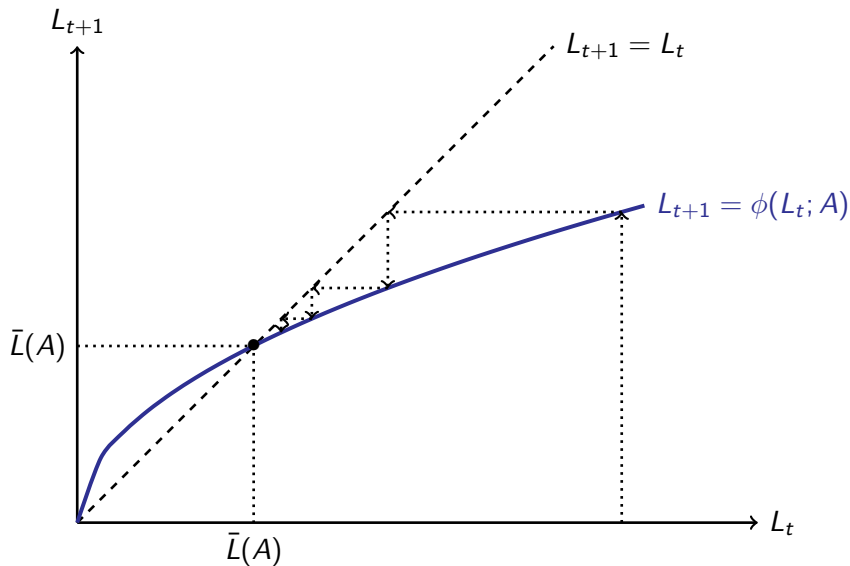


## Population Dynamics





## 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

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

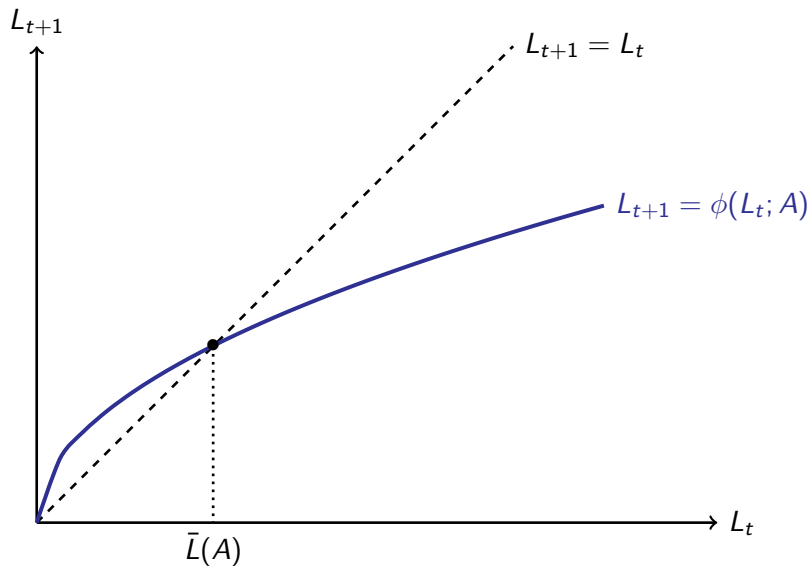
- Steady-State:  $L_{t+1} = L_t = \bar{L}$

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

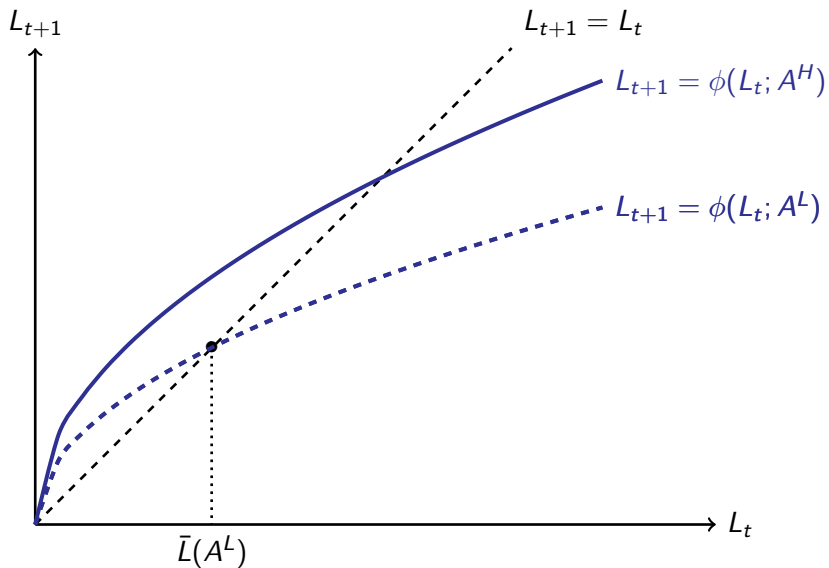
- The steady-state level of the size of the working population

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

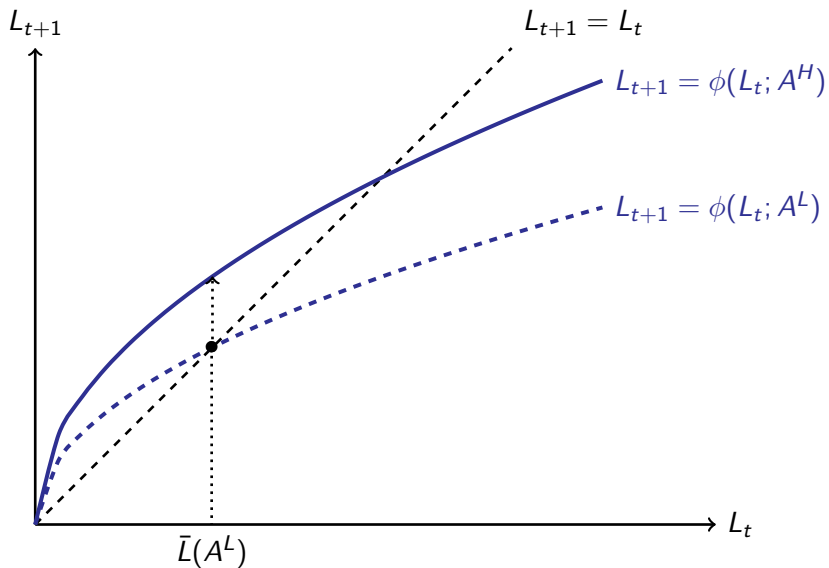
## Population Dynamics



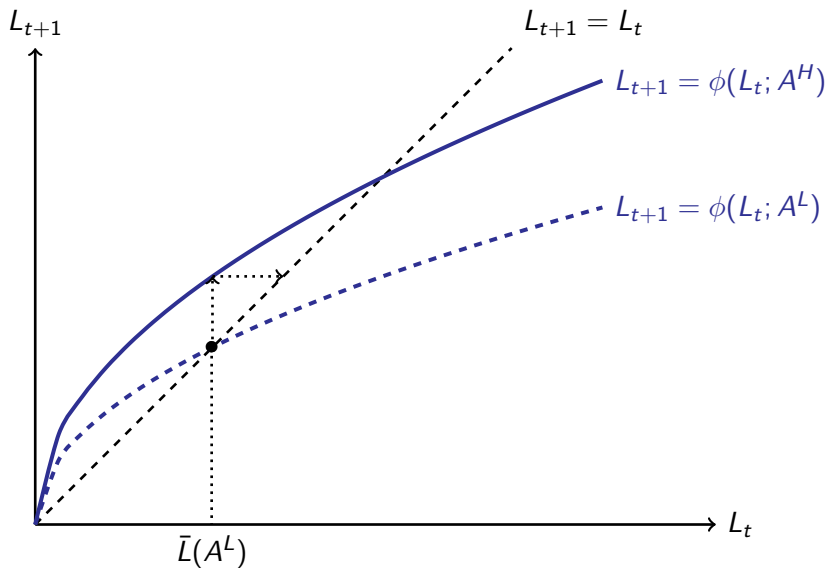
## Adjustment of Population to Advancements in Technology



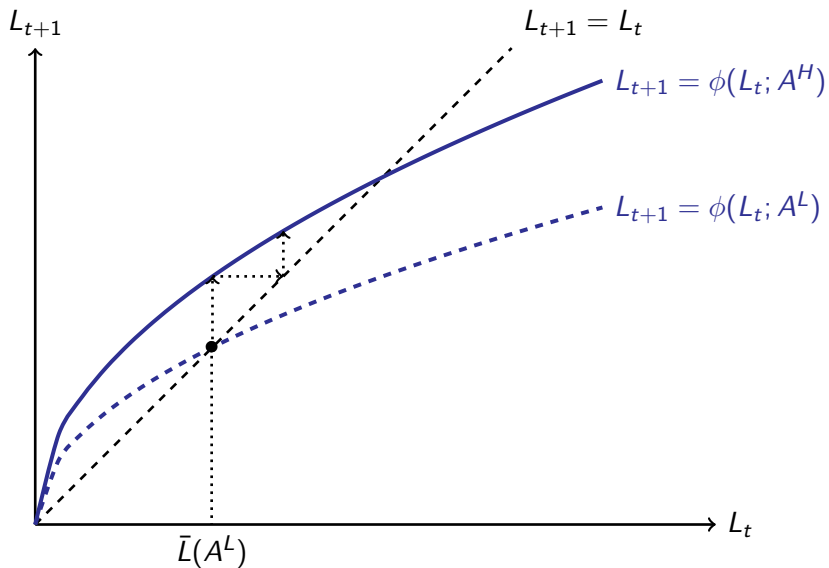
## Adjustment of Population to Advancements in Technology



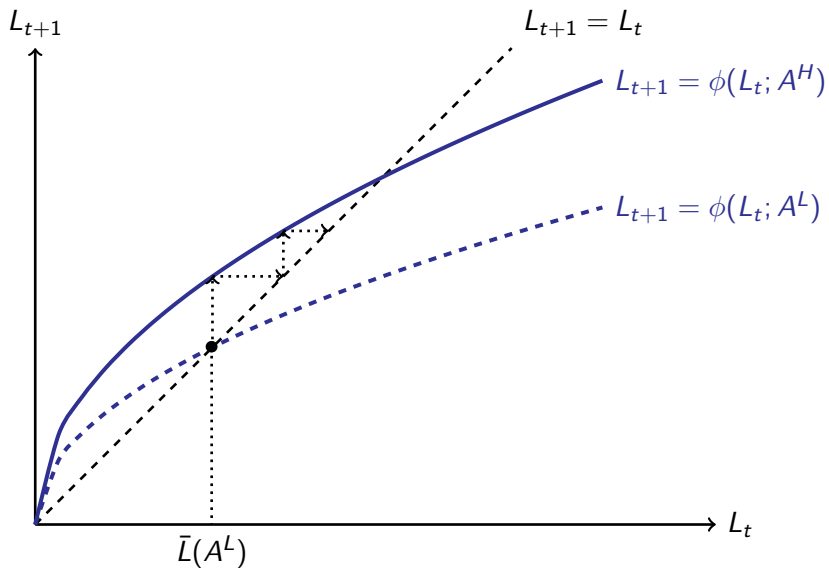
## Adjustment of Population to Advancements in Technology



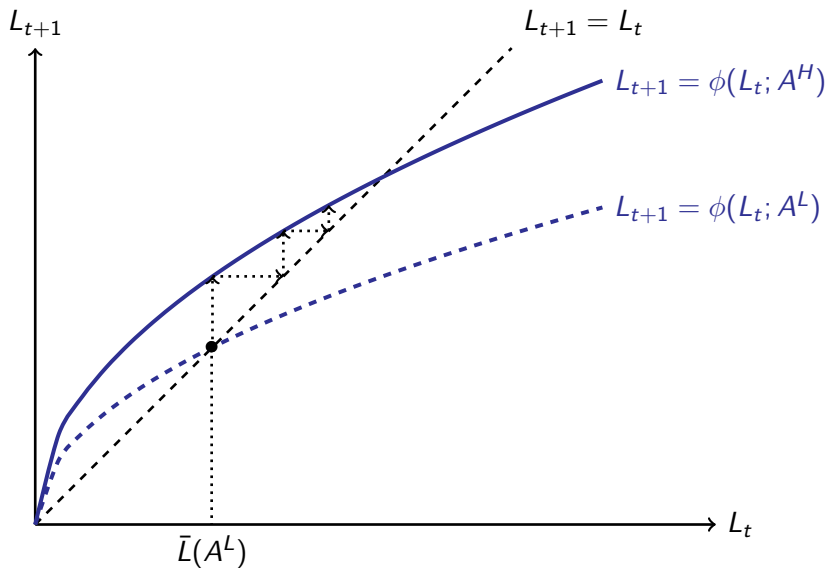
## Adjustment of Population to Advancements in Technology



## Adjustment of Population to Advancements in Technology

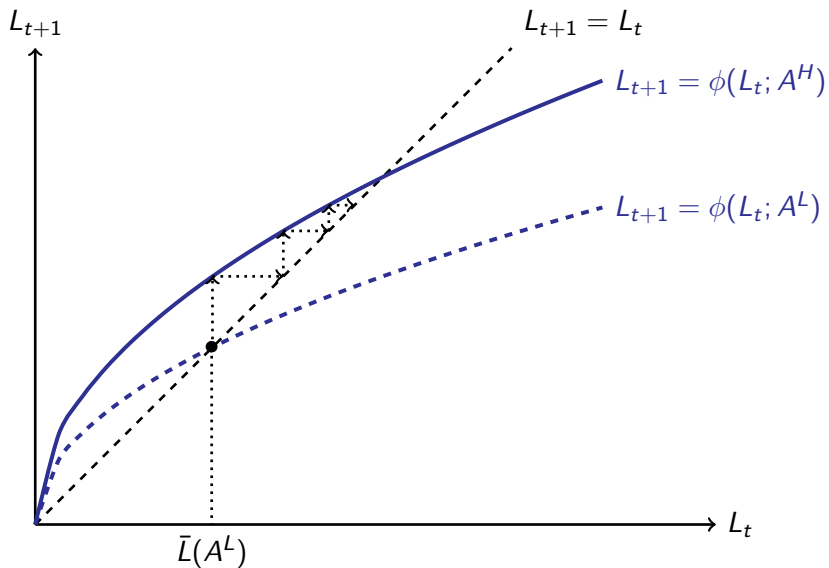


## Adjustment of Population to Advancements in Technology

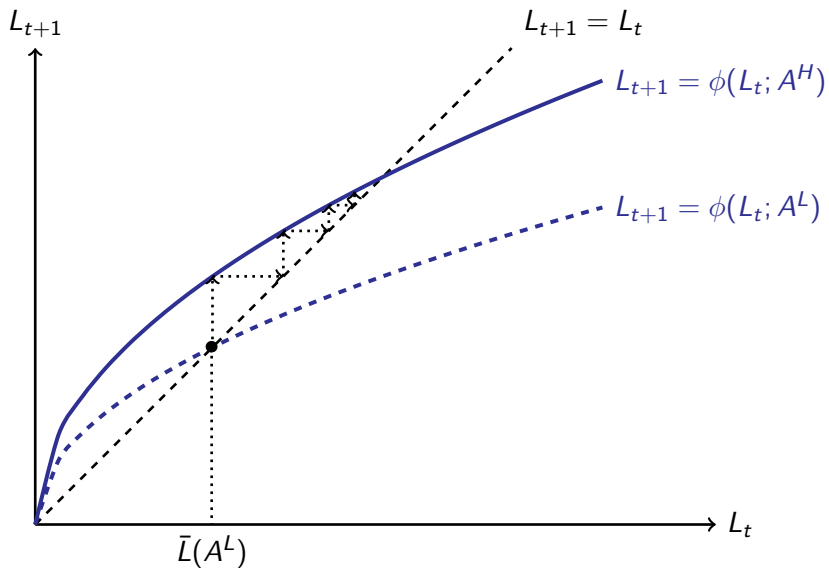




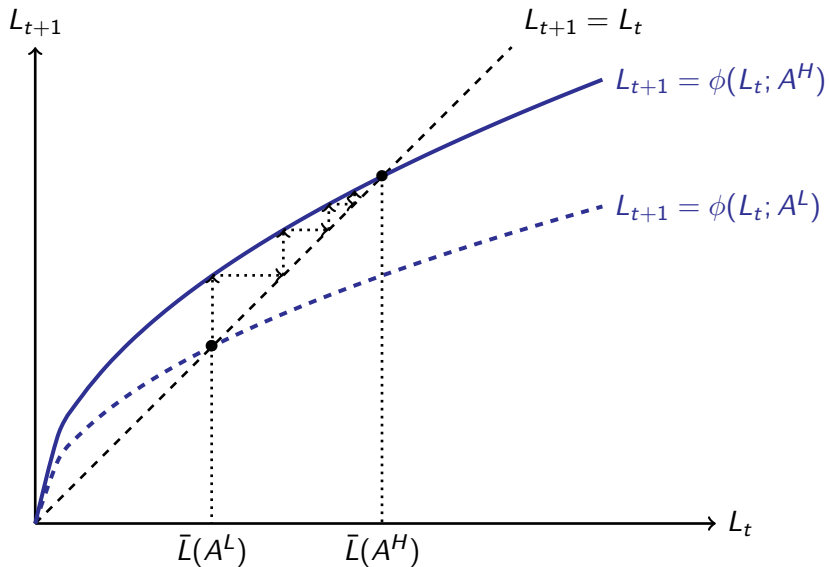
## Adjustment of Population to Advancements in Technology



## 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

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

$$y_{t+1} =$$

## 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

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

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

## 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

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

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

## 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

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

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

- Income dynamics

## 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

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

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

- Income dynamics

$$y_{t+1} =$$

## 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

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

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

- Income dynamics

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

## 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

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

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

- Income dynamics

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



## 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

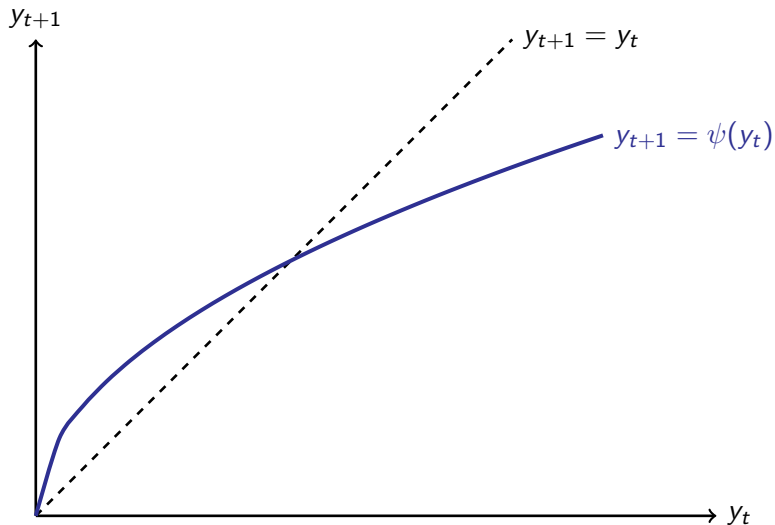
$$n_t = \frac{\gamma}{\rho} y_t$$

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

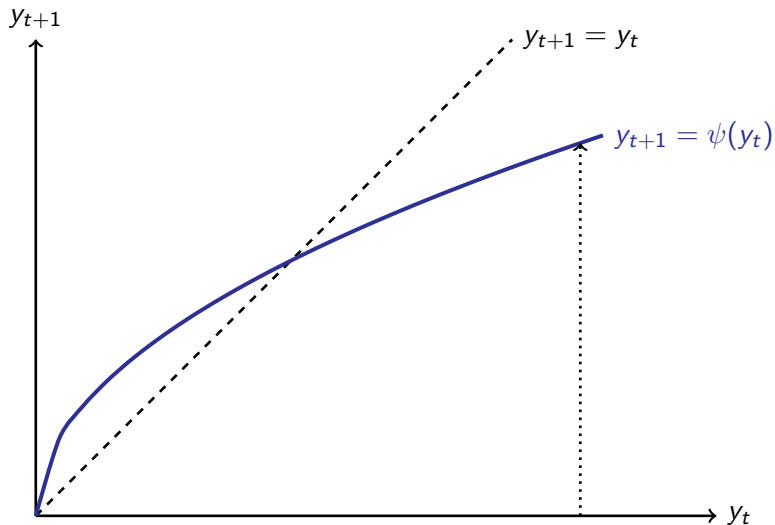
- Income dynamics

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

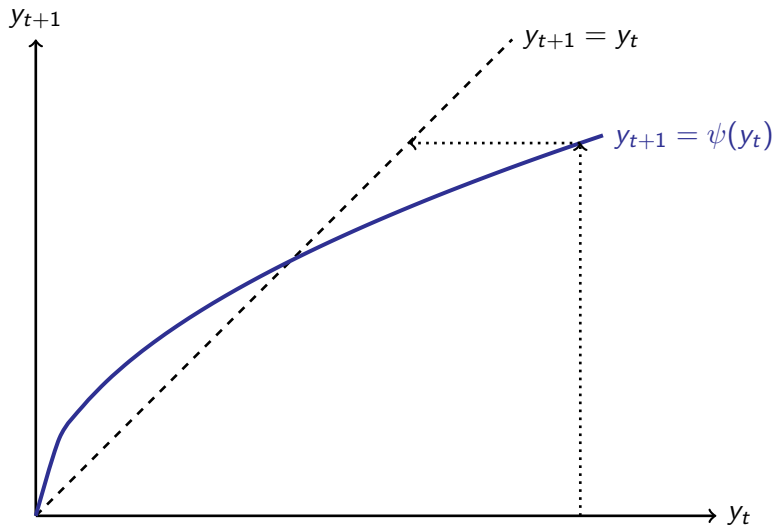
# The Evolution of Income per Worker



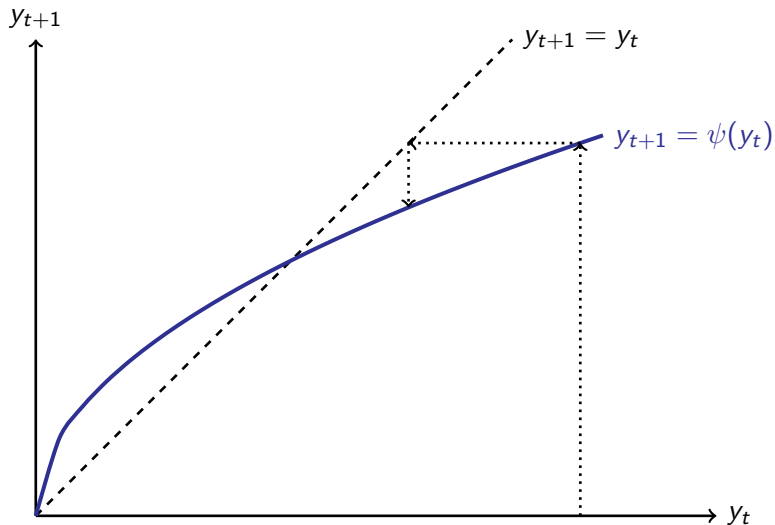
# The Evolution of Income per Worker



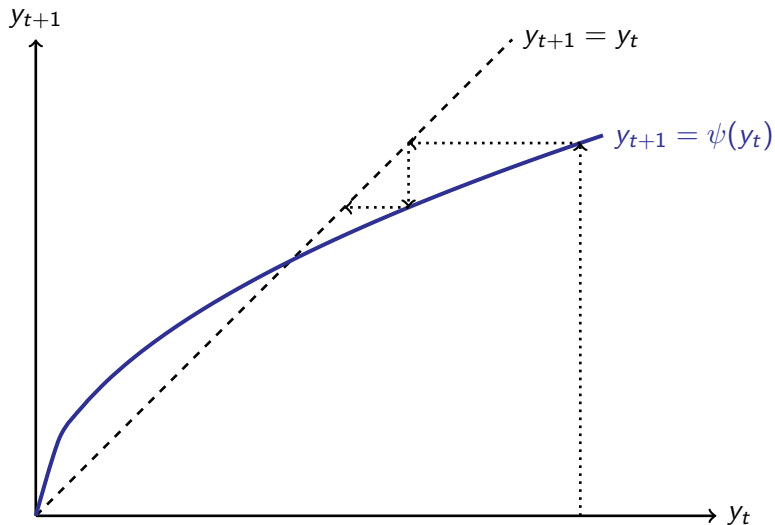
# The Evolution of Income per Worker



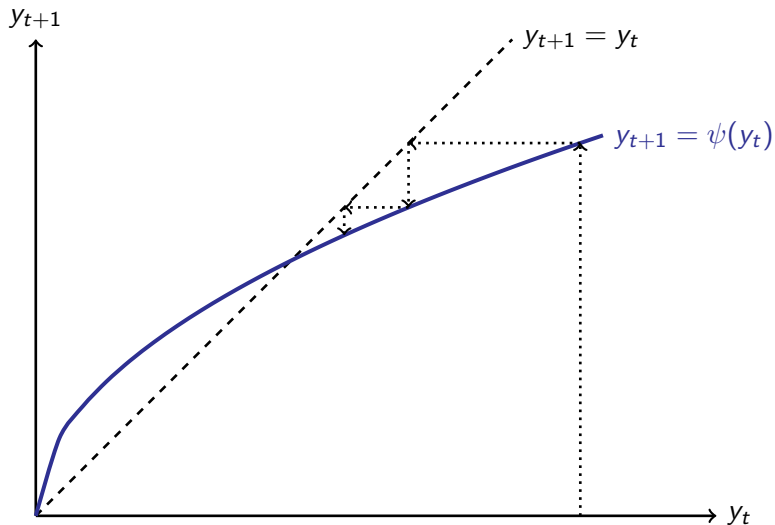
# The Evolution of Income per Worker



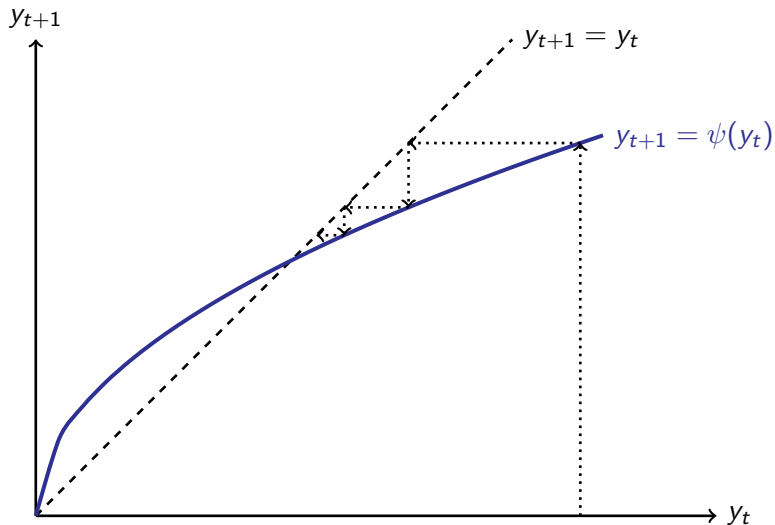
# The Evolution of Income per Worker



# The Evolution of Income per Worker

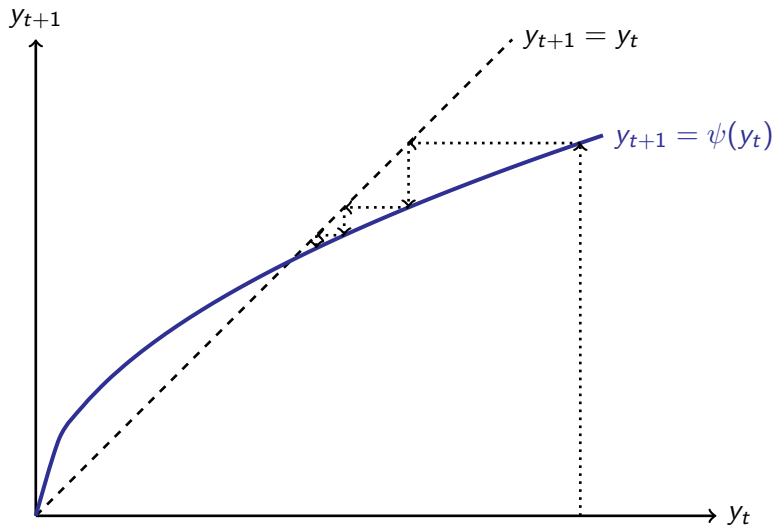


# The Evolution of Income per Worker

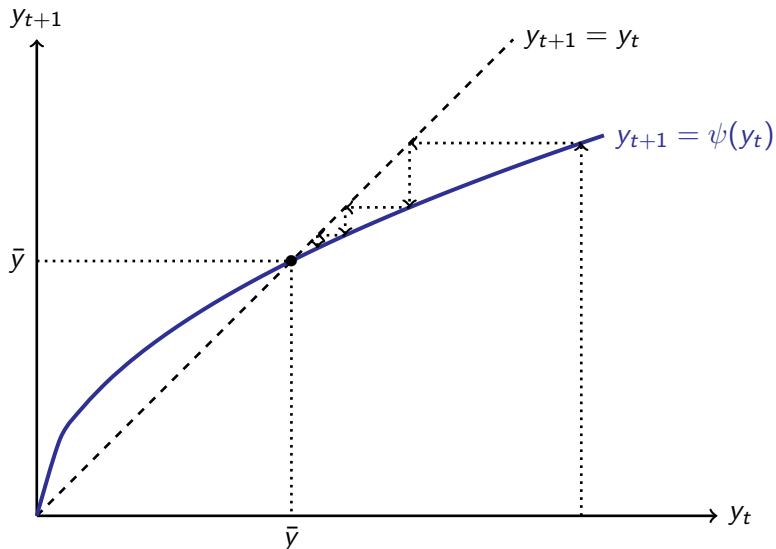




# The Evolution of Income per Worker



# 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

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

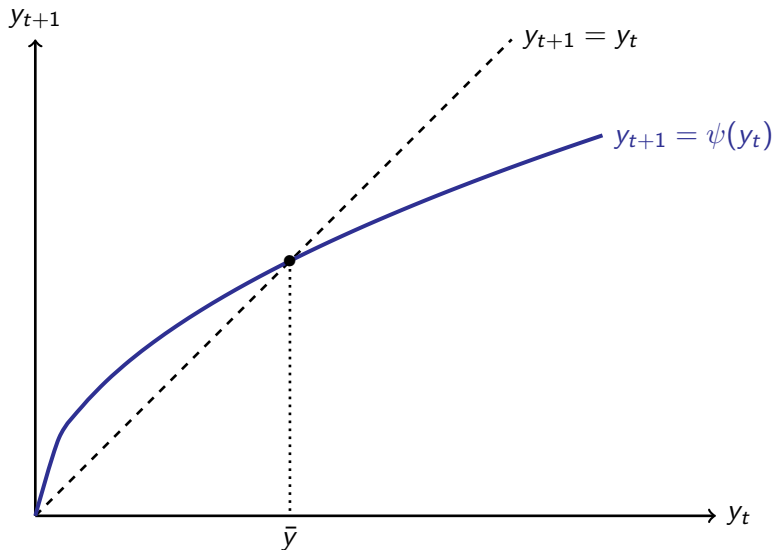
- Steady-State  $y_{t+1} = y_t = \bar{y}$

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

- The steady-state level of income per worker

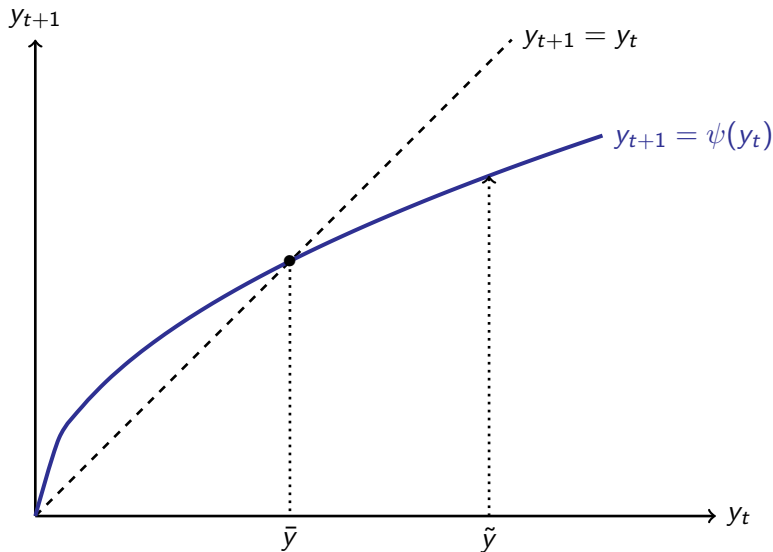
$$\bar{y} = \left[ \frac{\rho}{\gamma} \right]$$

# The Evolution of Income per Worker

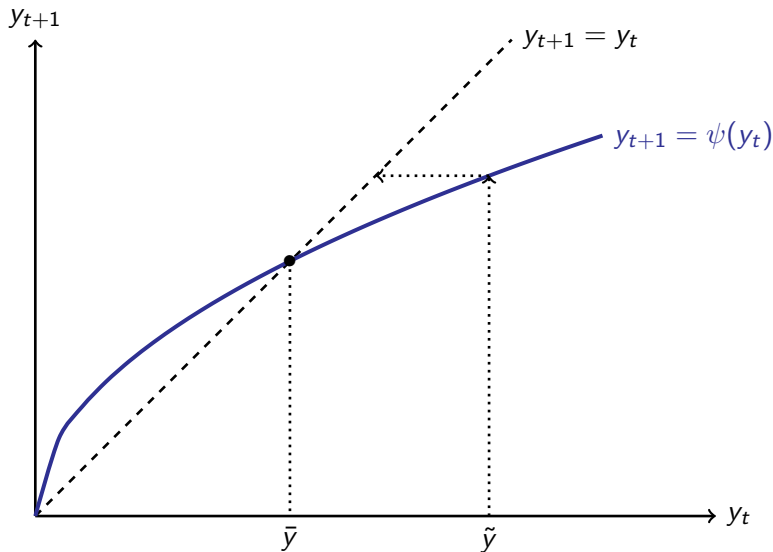




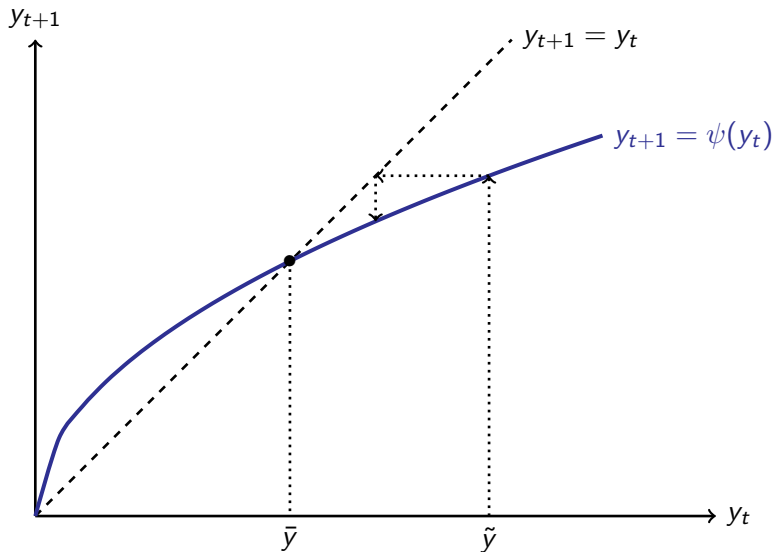
# The Effect of Technological Advancement on income per Worker



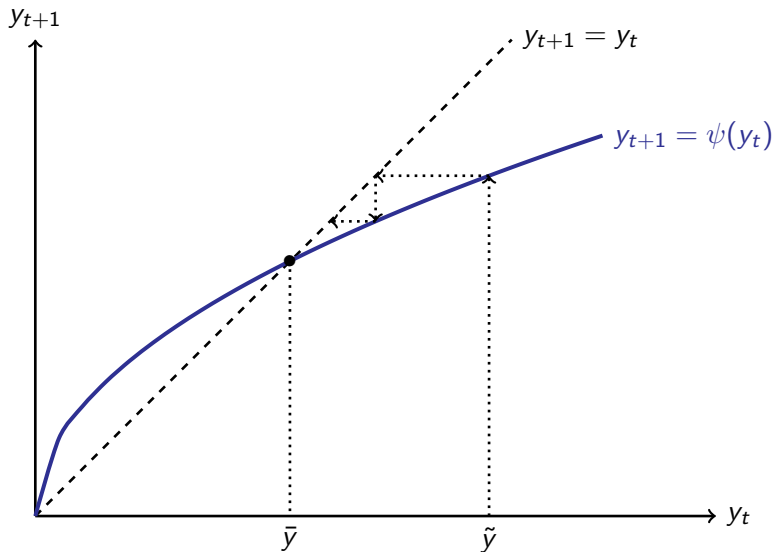
# The Effect of Technological Advancement on income per Worker



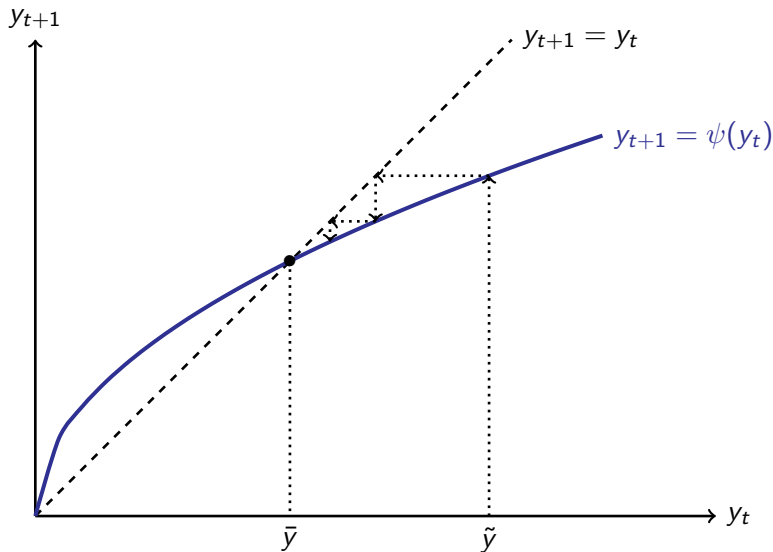
## The Effect of Technological Advancement on income per Worker



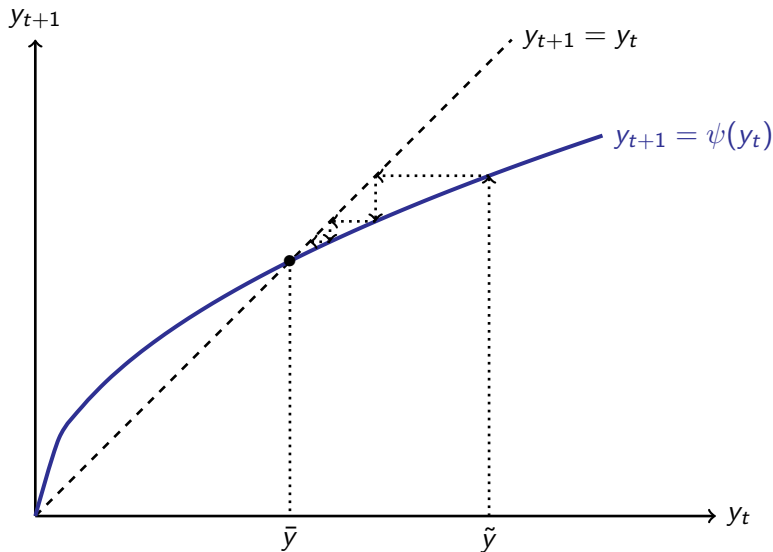
# The Effect of Technological Advancement on income per Worker



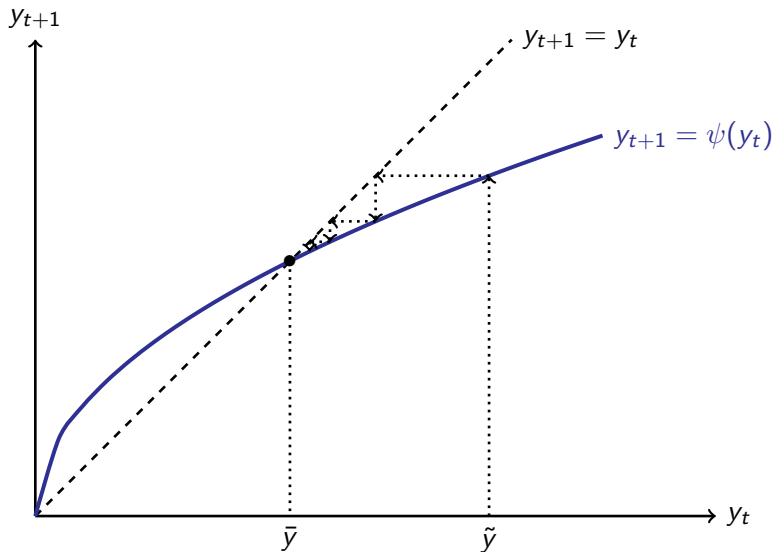
## The Effect of Technological Advancement on income per Worker



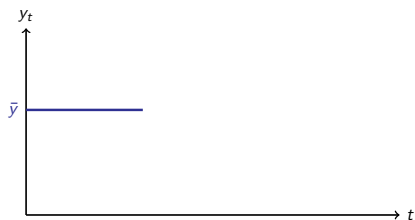
## The Effect of Technological Advancement on income per Worker



## The Effect of Technological Advancement on income per Worker

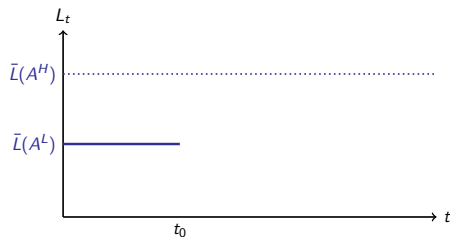
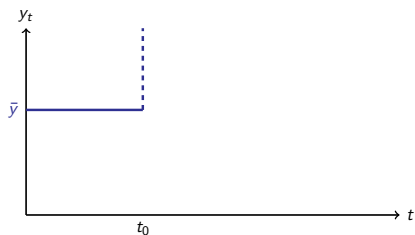


# The Effect of Technological Advancement on the Time Path of Population and Income per Worker

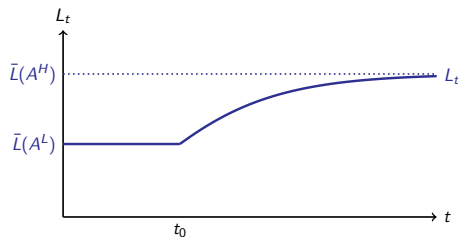
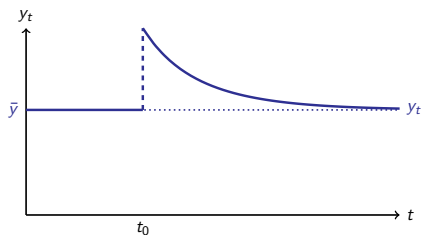




# The Effect of Technological Advancement on the Time Path of Population and Income per Worker



# The Effect of Technological Advancement on the Time Path of Population and Income per Worker



## The Effect of Advancement in Technology or Land Productivity

- Increases the short-run and the steady-state level of the working population

$$\frac{\partial L_t}{\partial A} > 0 \quad \text{and} \quad \frac{\partial \bar{L}}{\partial A} > 0$$

- Increases the level of income per capita in the short-run but does not affect the steady-state levels of income per worker

$$\frac{\partial y_t}{\partial A} > 0 \quad \text{and} \quad \frac{\partial \bar{y}}{\partial A} = 0$$

## Testable Implications

## Testable Implications

- Variations in technology and land quality across countries will be reflected primarily in variation in population density:

## Testable Implications

- Variations in technology and land quality across countries will be reflected primarily in variation in population density:
  - Technological superiority will result primarily in higher population density without any sizable effect on income per-capita in the long-run

## Testable Implications

- Variations in technology and land quality across countries will be reflected primarily in variation in population density:
  - Technological superiority will result primarily in higher population density without any sizable effect on income per-capita in the long-run
  - Superior land quality will result primarily in higher population density without any sizable effect on income per-capita in the long-run

## Empirical Hurdles

- Objective:



## Empirical Hurdles

- Objective:
  - Establish the causal effect of

## Empirical Hurdles

- Objective:
  - Establish the causal effect of
    - Technology on Population in 1500

## Empirical Hurdles

- Objective:
  - Establish the causal effect of
    - Technology on Population in 1500
- Hurdles

## Empirical Hurdles

- Objective:
  - Establish the causal effect of
    - Technology on Population in 1500
- Hurdles
  - Reverse Causality: Correlation between technology and population

## Empirical Hurdles

- Objective:
  - Establish the causal effect of
    - Technology on Population in 1500
- Hurdles
  - Reverse Causality: Correlation between technology and population
    - Technology  $\implies$  Population (Malthusian forces)

## Empirical Hurdles

- Objective:
  - Establish the causal effect of
    - Technology on Population in 1500
- Hurdles
  - Reverse Causality: Correlation between technology and population
    - Technology  $\implies$  Population (Malthusian forces)
    - Population  $\implies$  Technology (Scale effects in innovations)

## Empirical Hurdles

- Objective:
  - Establish the causal effect of
    - Technology on Population in 1500
- Hurdles
  - Reverse Causality: Correlation between technology and population
    - Technology  $\implies$  Population (Malthusian forces)
    - Population  $\implies$  Technology (Scale effects in innovations)
  - Omitted Variables Bias:

## Empirical Hurdles

- Objective:
  - Establish the causal effect of
    - Technology on Population in 1500
- Hurdles
  - Reverse Causality: Correlation between technology and population
    - Technology  $\implies$  Population (Malthusian forces)
    - Population  $\implies$  Technology (Scale effects in innovations)
  - Omitted Variables Bias:
    - 3rd factor (e.g., ability) affected Population & Technology



## 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 (thousands of years earlier):

## Identification Strategy

- Exploit exogenous sources of cross-country variation in technological level
  - Historical origins (thousands of years earlier):
    - unaffected by the population in 1500

## Identification Strategy

- Exploit exogenous sources of cross-country variation in technological level
  - Historical origins (thousands of years earlier):
    - unaffected by the population in 1500
  - Exogenous source of variations in these historical forces

## The Neolithic Origins of Comparative Development – Diamond's Hypothesis

- The transition from hunter-gatherer tribes to agricultural communities:

## The Neolithic Origins of Comparative Development – Diamond's Hypothesis

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

## The Neolithic Origins of Comparative Development – Diamond's Hypothesis

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

## The Neolithic Origins of Comparative Development – Diamond's Hypothesis

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



## The Neolithic Origins of Comparative Development – Diamond's Hypothesis

- The transition from hunter-gatherer tribes to agricultural communities:
  - Emergence of non-food-producing class:
    - $\implies$  Knowledge creation (science, technology & written languages)
  - Technological head start and its persistent effect via:
    - Urbanization, nation states, colonization

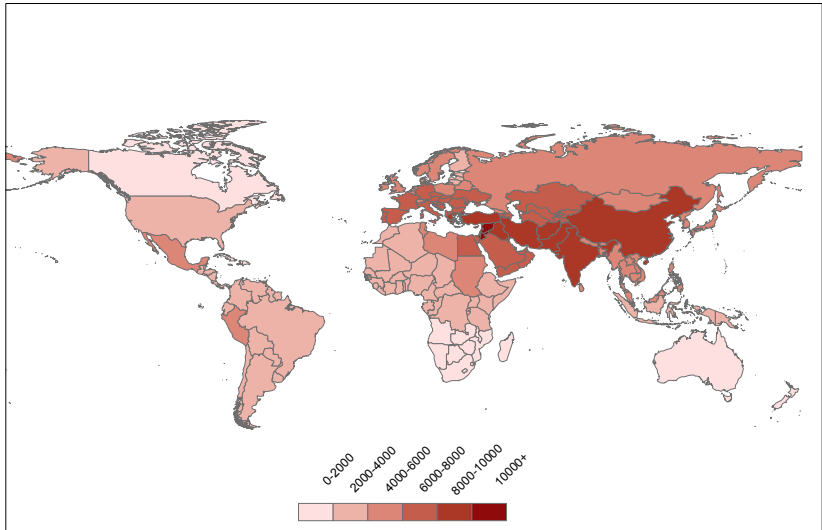
## The Neolithic Origins of Comparative Development – Diamond's Hypothesis

- The transition from hunter-gatherer tribes to agricultural communities:
  - Emergence of non-food-producing class:
    - $\implies$  Knowledge creation (science, technology & written languages)
  - Technological head start and its persistent effect via:
    - Urbanization, nation states, colonization
- Variations in biogeographical characteristics conducive for the NR :

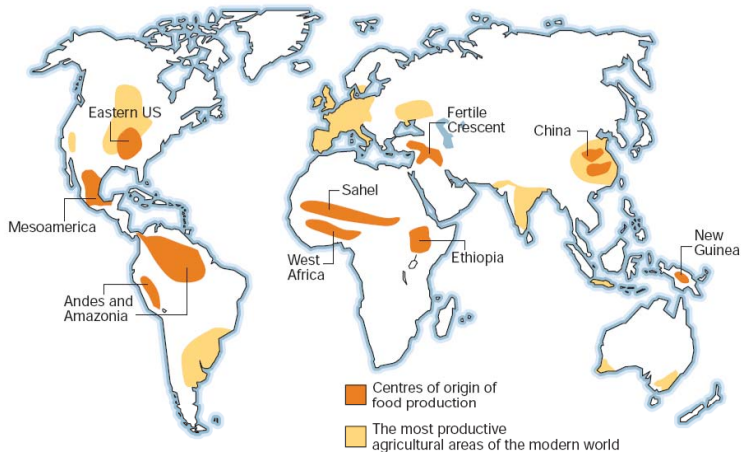
## The Neolithic Origins of Comparative Development – Diamond's Hypothesis

- The transition from hunter-gatherer tribes to agricultural communities:
  - Emergence of non-food-producing class:
    - $\Rightarrow$  Knowledge creation (science, technology & written languages)
  - Technological head start and its persistent effect via:
    - Urbanization, nation states, colonization
- Variations in biogeographical characteristics conducive for the NR :
  - $\Rightarrow$  Origins of the observed patterns of comparative development

## Variation in the Onset of the Neolithic Revolution



## Independent Origins



## Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors that maximized biodiversity (climate, latitude, landmass)

## Biogeographical Origins of the Onset of the Neolithic Revolution

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

## Biogeographical Origins of the Onset of the Neolithic Revolution

- Geographical factors that maximized biodiversity (climate, latitude, landmass)
  - Availability of domesticable species of plants and animals
    - $\Rightarrow$  Onset of domestication



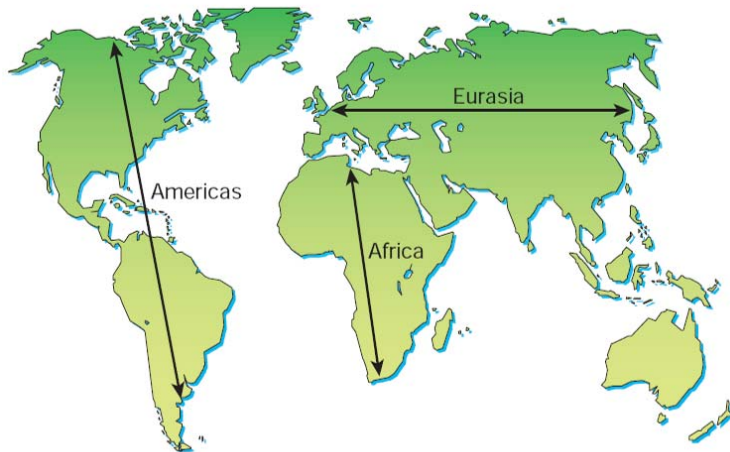
## Biogeographical Origins of the Onset of the Neolithic Revolution

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

## Biogeographical Origins of the Onset of the Neolithic Revolution

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

## Orientation of Continents



## 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
    - $\implies$  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
    - $\implies$  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
    - $\implies$  Technological head start and its effect on development
- Earlier onset of the Neolithic Revolution:
  - Technological superiority

## Identification Strategy

- Resolving: reverse causality

## Identification Strategy

- Resolving: reverse causality
  - Variation in the onset of the Neolithic Revolution (NR) across the globe - a proxy for variation in the technological level

## Identification Strategy

- Resolving: reverse causality
  - Variation in the onset of the Neolithic Revolution (NR) across the globe - a proxy for variation in the technological level
- Resolving: omitted variable bias (i.e., 3rd factor (e.g., ability)) affected population & NR

## Identification Strategy

- Resolving: reverse causality
  - Variation in the onset of the Neolithic Revolution (NR) across the globe - a proxy for variation in the technological level
- Resolving: omitted variable bias (i.e., 3rd factor (e.g., ability)) affected population & NR
  - Variation in prehistoric domesticable species of plants and animals – IV for the timing of the NR

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

	Technology Level 1000BCE-1500CE					
	1000BCE		1CE		1500CE	
	(1)	(2)	(3)	(4)	(5)	(6)
Years Since Neolithic Revolution	0.72*** (0.06)	0.47*** (0.12)	0.56*** (0.06)	0.28** (0.12)	0.74*** (0.06)	0.34*** (0.10)
Continental FE	No	Yes	No	Yes	No	Yes
Additional Geographical Controls	No	Yes	No	Yes	No	Yes
Adjusted- $R^2$	0.51	0.60	0.31	0.63	0.55	0.82
Observations	112	111	134	133	113	112

Notes: Standardized coefficients from an Ordinary Least Squares (OLS) regression. Heteroskedasticity robust standard error estimates are reported in parentheses; \*\*\* denotes statistical significance at the 1% level, \*\* at the 5% level, and \* at the 10% level, all for two-sided hypothesis tests.

## 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  $i$

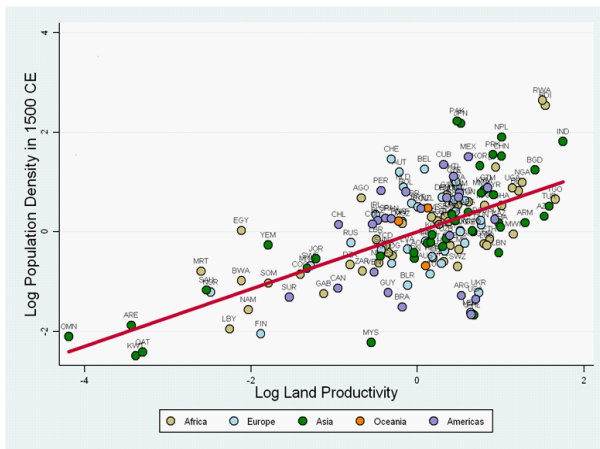
# Determinants of Population Density in 1500 CE

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	IV
Dependent Variable: Log population density in 1500 CE						
Log years since Neolithic	<b>0.833***</b> (0.298)		<b>1.025***</b> (0.223)	<b>1.087***</b> (0.184)	<b>1.389***</b> (0.224)	<b>2.077***</b> (0.391)
Log land productivity		<b>0.587***</b> (0.071)	<b>0.641***</b> (0.059)	<b>0.576***</b> (0.052)	<b>0.573***</b> (0.095)	<b>0.571***</b> (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 <sup>2</sup>	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						

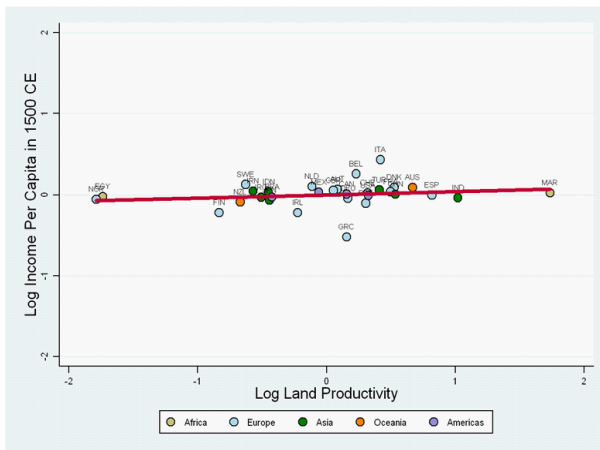
## Effects on Income per Capita versus Population Density

	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)
	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	<b>0.159</b> (0.136)	<b>0.073</b> (0.045)	<b>0.109</b> (0.072)	<b>1.337**</b> (0.594)	<b>0.832**</b> (0.363)	<b>1.006**</b> (0.483)
Log land productivity	<b>0.041</b> (0.025)	<b>-0.021</b> (0.025)	<b>-0.001</b> (0.027)	<b>0.584***</b> (0.159)	<b>0.364***</b> (0.110)	<b>0.681**</b> (0.255)
Log absolute latitude	-0.041 (0.073)	0.060 (0.147)	-0.175 (0.175)	0.050 (0.463)	-2.140** (0.801)	-2.163** (0.979)
Distance to nearest coast or river	0.215 (0.198)	-0.111 (0.138)	0.043 (0.159)	-0.429 (1.237)	-0.237 (0.751)	0.118 (0.883)
% land within 100 km of coast or river	0.124 (0.145)	-0.150 (0.121)	0.042 (0.127)	1.855** (0.820)	1.326** (0.615)	0.228 (0.919)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	31	26	29	31	26	29
R <sup>2</sup>	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

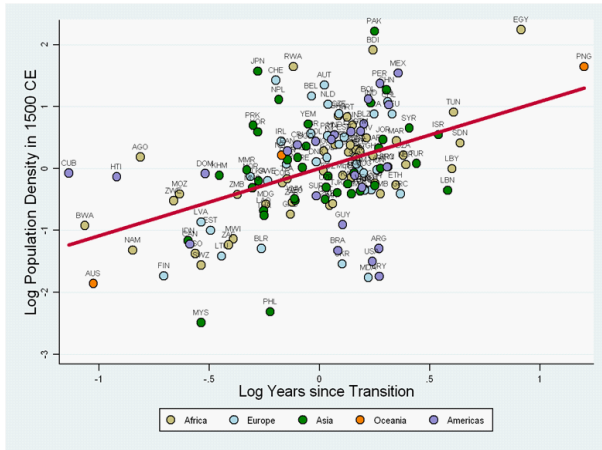


# Land Productivity and Income per Capita in 1500

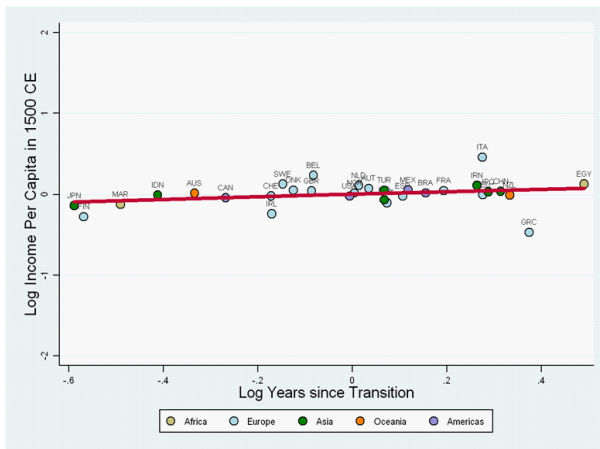




# Technology and Population Density in 1500



# Technology and Income per Capita in 1500



## 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
  - Variation in prehistoric biogeographic endowments – IV for this direct measure 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
  - Variation in prehistoric biogeographic endowments – IV for this direct measure of technology
- Robustness to the distance from the technological frontier

## Robustness of Identification Strategy

- Robustness to the inclusion of direct measures of technology
  - Exploit variation in a direct measure of the technology level
  - Variation in prehistoric biogeographic endowments – IV for this direct measure of technology
- Robustness to the distance from the technological frontier
- Robustness to the exclusion of unobserved time-invariant country fixed effects

## Robustness of Identification Strategy

- Robustness to the inclusion of direct measures of technology
  - Exploit variation in a direct measure of the technology level
  - Variation in prehistoric biogeographic endowments – IV for this direct measure of technology
- Robustness to the distance from the technological frontier
- Robustness to the exclusion of unobserved time-invariant country fixed effects
  - First-difference estimation strategy (with a lagged explanatory variable)



## Robustness of Identification Strategy

- Robustness to the inclusion of direct measures of technology
  - Exploit variation in a direct measure of the technology level
  - Variation in prehistoric biogeographic endowments – IV for this direct measure of technology
- Robustness to the distance from the technological frontier
- Robustness to the exclusion of unobserved time-invariant country fixed effects
  - First-difference estimation strategy (with a lagged explanatory variable)
  - The effect of changes in the level of technology in 1000 BCE-1 CE on population density and income per capita in 1-1000CE

# Robustness to Direct Measures of Technological Level

	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent Variable:					
	Log Population		Log Income Per		Log Population	
	Density in:		Capita in:		Density in:	
	1000 CE	1 CE	1000 CE	1 CE	1000 CE	1 CE
Log Technology Index in Relevant Period	4.315*** (0.850)	4.216*** (0.745)	0.064 (0.230)	0.678 (0.432)	12.762*** (0.918)	7.461** (3.181)
Log land productivity	0.449*** (0.056)	0.379*** (0.082)	-0.016 (0.030)	0.004 (0.033)	0.429** (0.182)	0.725** (0.303)
Log absolute latitude	-0.283** (0.120)	-0.051 (0.127)	0.036 (0.161)	-0.198 (0.176)	-1.919*** (0.576)	-2.350*** (0.784)
Distance to nearest coast or river	-0.638*** (0.188)	-0.782*** (0.198)	-0.092 (0.144)	0.114 (0.164)	0.609 (0.469)	0.886 (0.904)
% land within 100 km of coast or river	0.385 (0.313)	0.237 (0.329)	-0.156 (0.139)	0.092 (0.136)	1.265** (0.555)	0.788 (0.934)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	140	129	26	29	26	29
R <sup>2</sup>	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)
Dependent Variable: Population Density in:						
	1000CE			1CE		
Log Technology Index in Relevant Period	4.315*** (0.850)	4.198*** (1.164)	14.530*** (4.437)	4.216*** (0.745)	3.947*** (0.983)	10.798*** (2.857)
Log land productivity	0.449*** (0.056)	0.498*** (0.139)	0.572*** (0.148)	0.379*** (0.082)	0.350** (0.172)	0.464** (0.182)
Log absolute latitude	-0.283** (0.120)	-0.185 (0.151)	-0.209 (0.209)	-0.051 (0.127)	0.083 (0.170)	-0.052 (0.214)
Distance to nearest coast or river	-0.638*** (0.188)	-0.363 (0.426)	-1.155* (0.640)	-0.782*** (0.198)	-0.625 (0.434)	-0.616 (0.834)
% land within 100 km of coast or river	0.385 (0.313)	0.442 (0.422)	0.153 (0.606)	0.237 (0.329)	0.146 (0.424)	-0.172 (0.642)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	140	92	92	129	83	83
R <sup>2</sup>	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*** (0.208)	0.877*** (0.214)	0.117 (0.221)	0.103 (0.214)	1.498** (0.546)	1.478** (0.556)
Log land productivity	0.559*** (0.048)	0.545*** (0.063)	0.036 (0.032)	0.047 (0.037)	0.596*** (0.123)	0.691*** (0.122)
Log Distance to Frontier	-0.186*** (0.035)	-0.191*** (0.036)	-0.005 (0.011)	-0.001 (0.013)	-0.130* (0.066)	-0.108* (0.055)
Small Island Dummy	0.067 (0.582)	0.086 (0.626)	-0.118 (0.216)	-0.046 (0.198)	1.962** (0.709)	2.720*** (0.699)
Landlocked Dummy	0.131 (0.209)	0.119 (0.203)	0.056 (0.084)	0.024 (0.101)	1.490*** (0.293)	1.269*** (0.282)
% Land in Temperate Climate Zones		-0.196 (0.513)		-0.192 (0.180)		-1.624* (0.917)
Continental dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	147	147	31	31	31	31
R <sup>2</sup>	0.76	0.76	0.67	0.67	0.94	0.96

## Conclusions

### Malthusian Hypothesis

- Population levels positively associated with

## Conclusions

### Malthusian Hypothesis

- Population levels positively associated with
  - Technology

## Conclusions

### Malthusian Hypothesis

- Population levels positively associated with
  - Technology
  - Land Productivity

## Conclusions

### Malthusian Hypothesis

- Population levels positively associated with
  - Technology
  - Land Productivity
- Income per capita levels



## Conclusions

### Malthusian Hypothesis

- Population levels positively associated with
  - Technology
  - Land Productivity
- Income per capita levels
  - Independent of both

## Conclusions

### Malthusian Hypothesis

- Population levels positively associated with
  - Technology
  - Land Productivity
- Income per capita levels
  - Independent of both
  - Determined by preferences for children