Economics 2
Spring 2017

Professor Christina Romer
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LECTURE 16
TECHNOLOGICAL CHANGE AND ECONOMIC GROWTH
March 14, 2017

I. OVERVIEW
   A. Long-run trend and short-run fluctuations in real GDP
   B. Potential output (Y*)
   C. Level and growth rate of potential output per person (Y*/POP)

II. FACTS ABOUT POTENTIAL OUTPUT PER PERSON
   A. Tremendous variation across countries
   B. Substantial increases over time
   C. Discussion of the paper by William Nordhaus

III. AGGREGATE PRODUCTION FUNCTION
   A. Decomposition of Y*/POP into normal average labor productivity (Y*/N*) and the normal employment-to-population ratio (N*/POP)
   B. N*/POP is largely determined by non-economic factors (such as demographics)
   C. Determinants of average labor productivity: capital per worker and technology

IV. EXPLAINING THE VARIATION IN THE LEVEL OF Y*/POP ACROSS COUNTRIES
   A. Limited contribution of N*/POP
   B. Crucial role of normal capital per worker (K*/N*)
   C. Crucial role for technology—especially institutions

V. DETERMINANTS OF ECONOMIC GROWTH
   A. Limited contribution of N*/POP
   B. Important, but limited contribution of K*/N*
   C. Crucial role of technological change

VI. HISTORICAL EVIDENCE OF TECHNOLOGICAL CHANGE
   A. New production techniques
   B. New goods
   C. Better institutions

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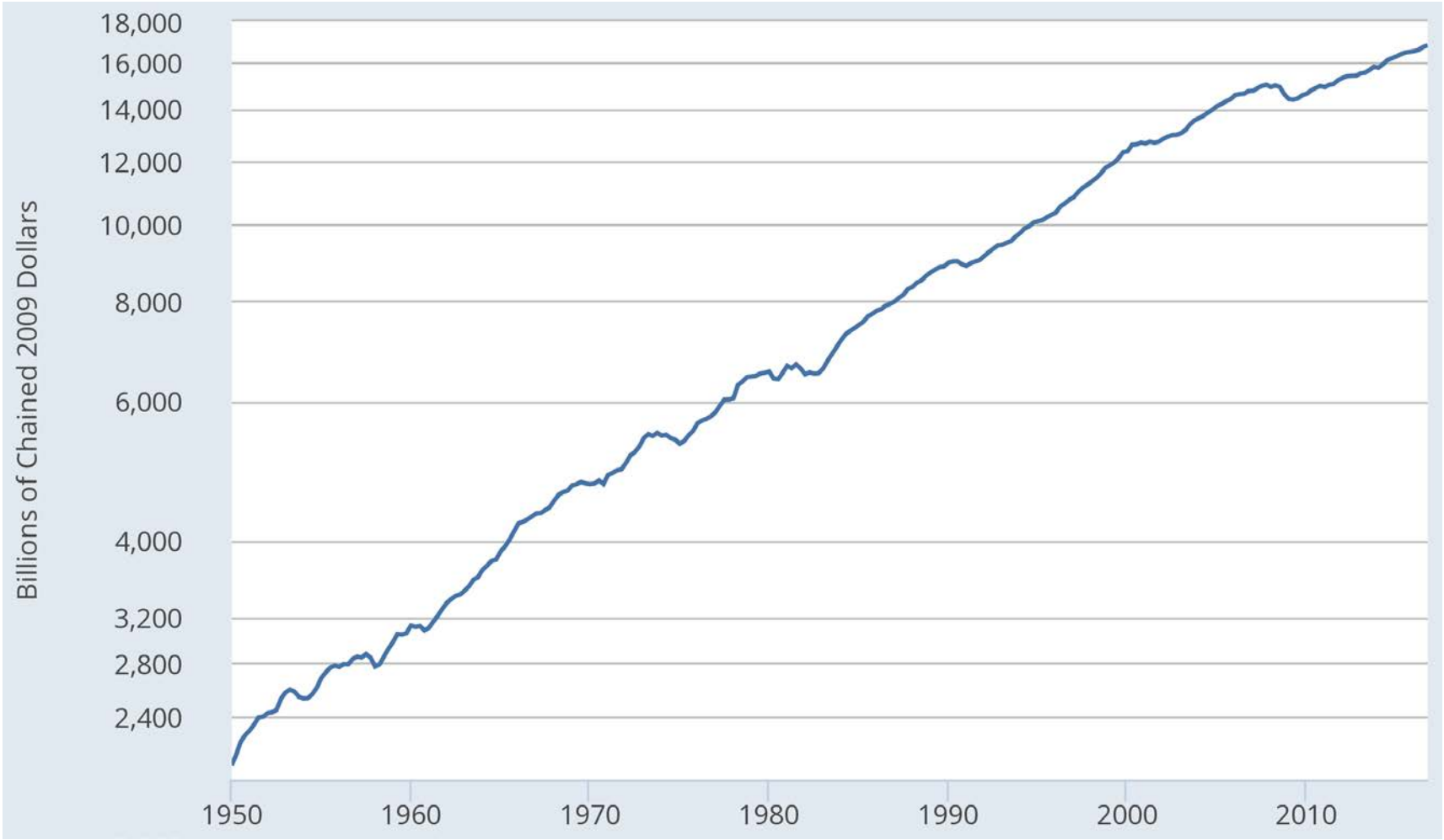
Announcement

- Problem Set 4 is being handed out.
  - It is due at the beginning of lecture next Tuesday (March 21).
  - The ground rules are the same as on previous problem sets.
  - Optional problem set work session: Friday, 4:00–6:00, in 648 Evans.

I. Overview

Real GDP in the United States, 1950–2016



Source: FRED (Federal Reserve Economic Data); data from Bureau of Economic Analysis.

Two Key Topics of Macroeconomics

- The long-run trend in output.
- Short-run fluctuations (booms and recessions).

Potential Output (Y*)

- The amount of output that the economy can produce when using its resources at normal rates.
- Determinants of Potential Output:
  - Labor
  - Capital
  - Technology
- A better name for potential output might be "normal output."

Issues Relating to Potential Output

- The ***level*** of potential output per person.
  - This is an indicator of standards of living.
  - Why is potential output per person so much higher in some countries than in others?
- The ***growth rate*** of potential output per person over time.
  - Small differences in normal growth can have large impacts on standards of living over time.

II. Facts about Potential Output per Person

TABLE 1.1 STATISTICS ON GROWTH AND DEVELOPMENT

	GDP per capita, 2008	GDP per worker, 2008	Labor force participation rate, 2008	Average annual growth rate, 1960–2008	Years to double
"Rich" countries					
United States	$43,326	$84,771	0.51	1.6	43
Japan	33,735	64,778	0.52	3.4	21
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"Poor" countries					
China	6,415	10,938	0.59	5.6	13
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"Growth miracles"					
Hong Kong	37,834	70,940	0.53	4.3	16
Singapore	49,987	92,634	0.54	4.1	17
Taiwan	29,645	62,610	0.47	5.1	14
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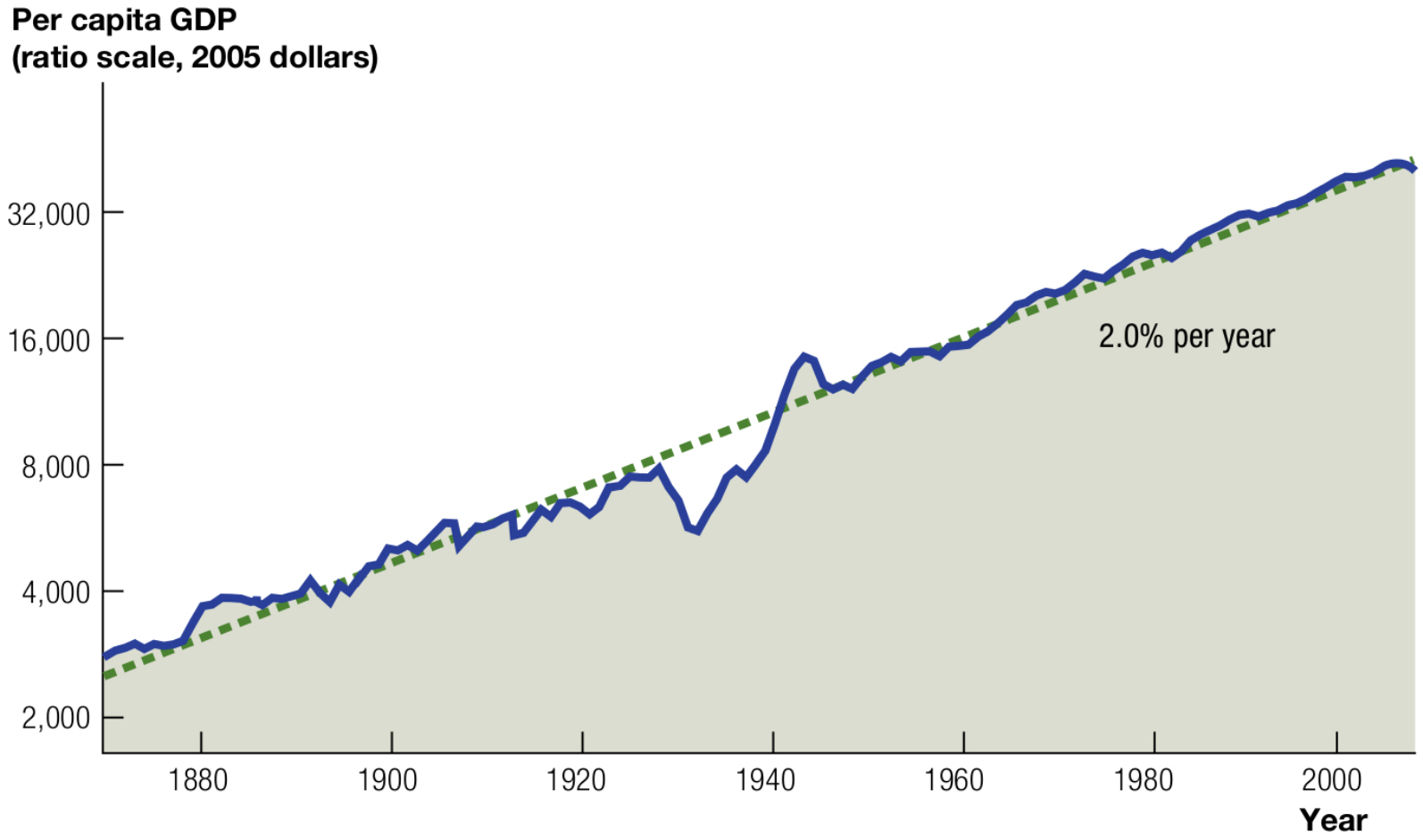
"Growth disasters"					
Venezuela	9,762	21,439	0.46	−0.1	−627
Haiti	1,403	3,164	0.44	−0.4	−168
Madagascar	810	1,656	0.49	−0.1	−488
Zimbabwe	135	343	0.40	−1.5	−47

Source: Charles Jones and Dietrich Vollrath, *Economic Growth*.

GDP per Capita in the U.S. Since 1870

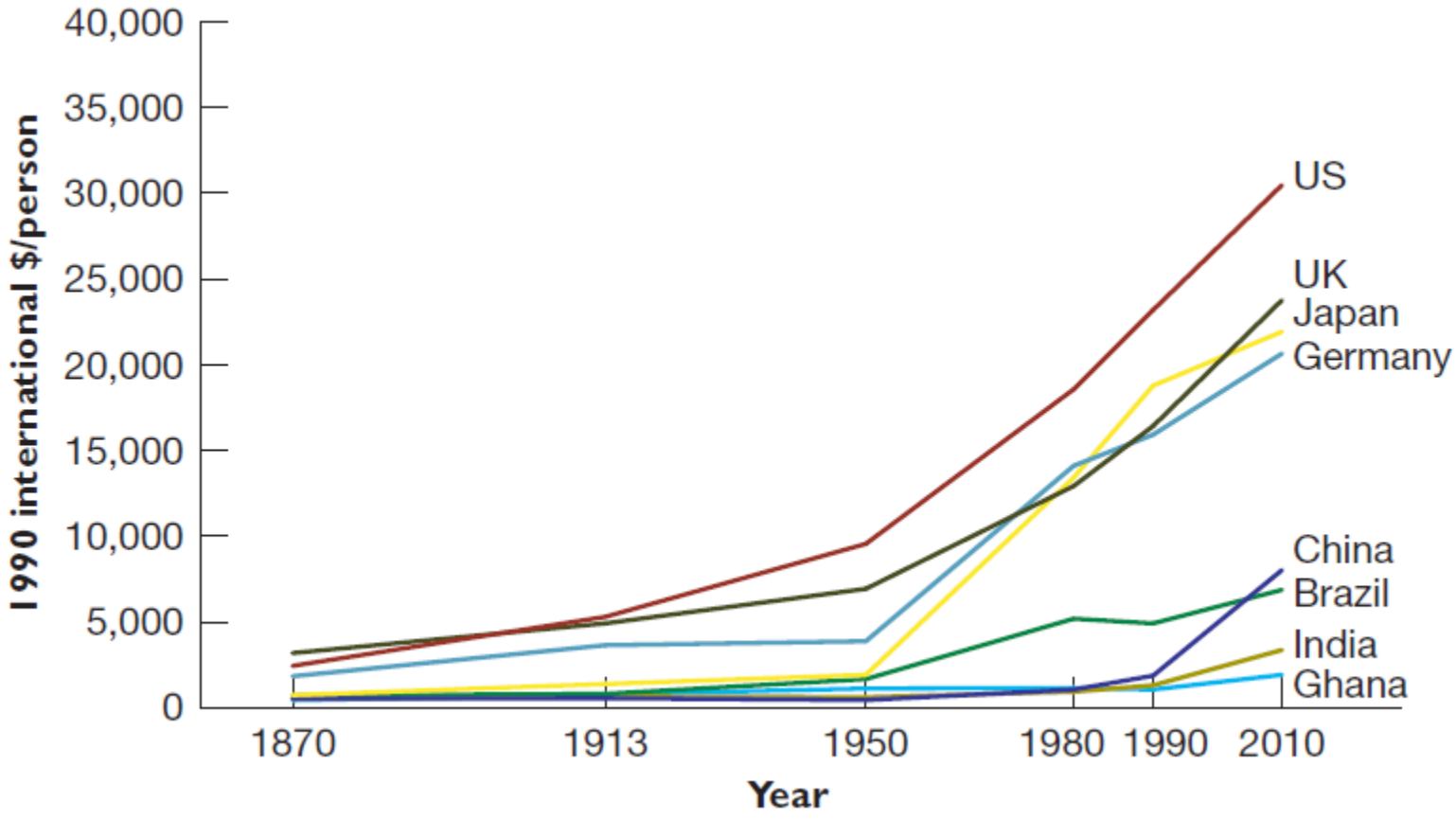


Source: Charles Jones, "Growth and Ideas."

Economic Growth

- Sustained increases in potential output per person.

GDP per Capita in 8 Countries since 1870



Source: Frank, Bernanke, Antonovics, and Heffetz, *Principles of Economics*.

Paper by William Nordhaus

- Argues that growth of real GDP in U.S. over the last two centuries may have been faster than conventionally measured.

- Related to mismeasurement in price indexes.

Consumer Price Index

- A measure of the overall or aggregate level of prices.

$$CPI_t = \frac{\text{Price of market basket in year t}}{\text{Price of market basket in base year}}$$

Paper by William Nordhaus

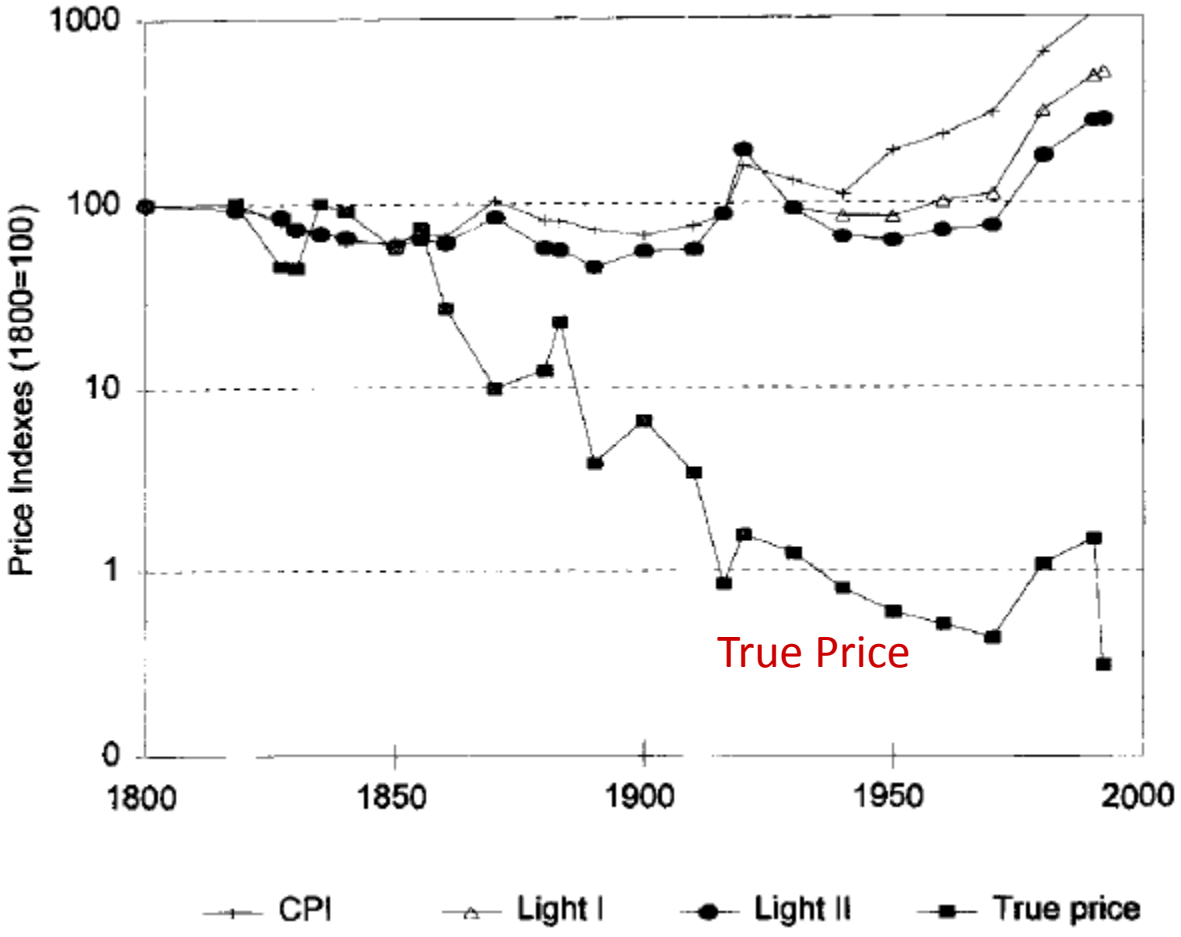
- What problems does Nordhaus see with typical price measures?
    - There may be quality changes.
    - New goods are being introduced all the time.
- What example does he use to illustrate the likely importance of these problems?
    - Lighting.

Table 1.3 Efficiency of Different Lighting Technologies

Device	Stage of Technology	Approximate Date	Lighting Efficiency (lumens per watt)	Lighting Efficiency (lumen-hours per 1,000 Btu)
Open fire[a]	Wood	From earliest time	0.00235	0.69
Neolithic lamp[b]	Animal or vegetable fat	38,000–9000 B.C.	0.0151	4.4
Babylonian lamp[a]	Sesame oil	1750 B.C.	0.0597	17.5
Candle[c]	Tallow	1800	0.0757	22.2
	Sperm	1800	0.1009	29.6
	Tallow	1830	0.0757	22.2
	Sperm	1830	0.1009	29.6
Lamp	Whale oil[d]	1815–45	0.1346	39.4
	Silliman's experiment: Sperm oil[e]	1855	0.0784	23.0
	Silliman's experiment: Other oils[f]	1855	0.0575	16.9
Town gas	Early lamp[g]	1827	0.1303	38.2
	Silliman's experiment[e]	1855	0.0833	24.4
	Early lamp[e]	1875–85	0.2464	72.2
	Welsbach mantle[e]	1885–95	0.5914	173.3
	Welsbach mantle[e]	1916	0.8685	254.5
Kerosene lamp	Silliman's experiment[e]	1855	0.0498	14.6
	19th century[h]	1875–85	0.1590	46.6
	Coleman lantern[i]	1993	0.3651	107.0
Electric lamp				
Edison carbon	Filament lamp[j]	1883	2.6000	762.0
Advanced carbon	Filament lamp[j]	1900	3.7143	1,088.6
	Filament lamp[j]	1910	6.5000	1,905.0
Tungsten	Filament lamp[j]	1920	11.8182	3,463.7
	Filament lamp[j]	1930	11.8432	3,471.0
	Filament lamp[j]	1940	11.9000	3,487.7
	Filament lamp[k]	1950	11.9250	3,495.0
	Filament lamp[k]	1960	11.9500	3,502.3
	Filament lamp[k]	1970	11.9750	3,509.7
	Filament lamp[k]	1980	12.0000	3,517.0
	Filament lamp[l]	1990	14.1667	4,152.0
Compact fluorescent	First generation bulb[m]	1992	68.2778	20,011.1

Source: Nordhaus, "Do Real-Output and Real-Wage Measures Capture Reality?"

Alternative Light Prices



Source: Nordhaus, "Do Real-Output and Real-Wage Measures Capture Reality?"

Economists' Definition of "Real"

- Measured in terms of goods and services, rather than dollars.
- Equivalently: Adjusted for changes in prices.
- For example, if our base year is 2009, real GDP is measured in terms of 2009 goods and services.

Why Mismeasurement of Inflation Leads to Mismeasurement of Growth

$$\frac{\text{Real GDP in year } t_2}{\text{Real GDP in year } t_1} = \frac{\dfrac{\text{Nominal GDP}_{t_2}}{\text{GDP Price Index}_{t_2}}}{\dfrac{\text{Nominal GDP}_{t_1}}{\text{GDP Price Index}_{t_1}}}$$

$$= \frac{\text{Nominal GDP}_{t_2}}{\text{Nominal GDP}_{t_1}} \bullet \frac{\text{GDP Price Index}_{t_1}}{\text{GDP Price Index}_{t_2}}$$

- If the growth of the price index from year t_1 to year t_2 is overstated, the growth of real GDP is understated.
- The same argument applies to the growth of real wages.

Were You Persuaded by Nordhaus?

III. The Aggregate Production Function

Decomposition of Potential Output per Person

$$\frac{Y^*}{POP} = \frac{Y^*}{N^*} \bullet \frac{N^*}{POP}$$

where:

- Y^* is potential output;
- POP is population;
- N^* is normal employment.

- $\frac{N^*}{POP}$ is the normal employment-to-population ratio.
- $\frac{Y^*}{N^*}$ is normal average labor productivity.

The normal employment-to-population ratio is usually taken as given.

- That is, it is assumed to ***not*** be a function of other economic variables.
- It depends on things like the age composition of the population, tastes, etc.

Determinants of Average Labor Productivity

$$\frac{Y^*}{N^*} = f\left(\frac{K^*}{N^*}, T\right)$$

- $\frac{K^*}{N^*}$ is normal capital per worker.
- T is technology.

Capital

- Man-made aids to the production process.
- Components of Capital:
  - Physical capital (machines, buildings, computers)
  - Infrastructure (roads, telecommunications systems, dams)
  - Human capital (education, job training)

Technology

- The methods for producing things.
- Components of Technology:
  - Production techniques
  - Management techniques
  - Economic institutions
  - Local culture

Aggregate Production Function

(1) $$\frac{Y^*}{POP} = \frac{Y^*}{N^*} \bullet \frac{N^*}{POP}$$

(2) $$\frac{Y^*}{N^*} = f\left(\frac{K^*}{N^*}, T\right)$$

(3) $$\frac{Y^*}{POP} = f\left(\frac{K^*}{N^*}, T\right) \bullet \frac{N^*}{POP}$$

IV. Explaining the Variation in the Level of Potential Output per Person across Countries

Contribution of the Employment-to-Population Ratio

$$\frac{Y^*}{POP} = f\left(\frac{K^*}{N^*}, T\right) \bullet \frac{N^*}{POP}$$

- It can certainly matter, but its effects are limited.
- It doesn't vary that much across countries.

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Source: Charles Jones and Dietrich Vollrath, *Economic Growth*.

Contribution of Capital per Worker

$$\frac{Y^*}{POP} = f\left(\frac{K^*}{N^*}, T\right) \bullet \frac{N^*}{POP}$$

- Physical and human capital does vary a lot across countries.
- And likely explains about half of the variation in normal output per capita across countries.

GDP Statistics for Selected Countries

	GDP per Capita	Physical Capital per Worker	Human Capital per Worker (Index)
"Rich" countries			
U.S.A	43,326	292,614	3.62
Japan	33,735	297,337	3.27
France	31,980	327,397	3.04
U.K.	35,345	222,377	2.82
"Poor" countries			
China	6,415	57,700	2.58
India	3,078	20,373	1.93
Nigeria	1,963	8,516	n.a.
Uganda	1,122	n.a.	1.98
"Growth miracles"			
Hong Kong	37,834	293,414	3.01
Singapore	49,987	309,148	2.77
Taiwan	29,645	179,589	3.21
South Korea	25,539	234,288	3.35
"Growth disasters"			
Venezuela	9,762	91,882	2.34
Zimbabwe	135	1,288	2.48

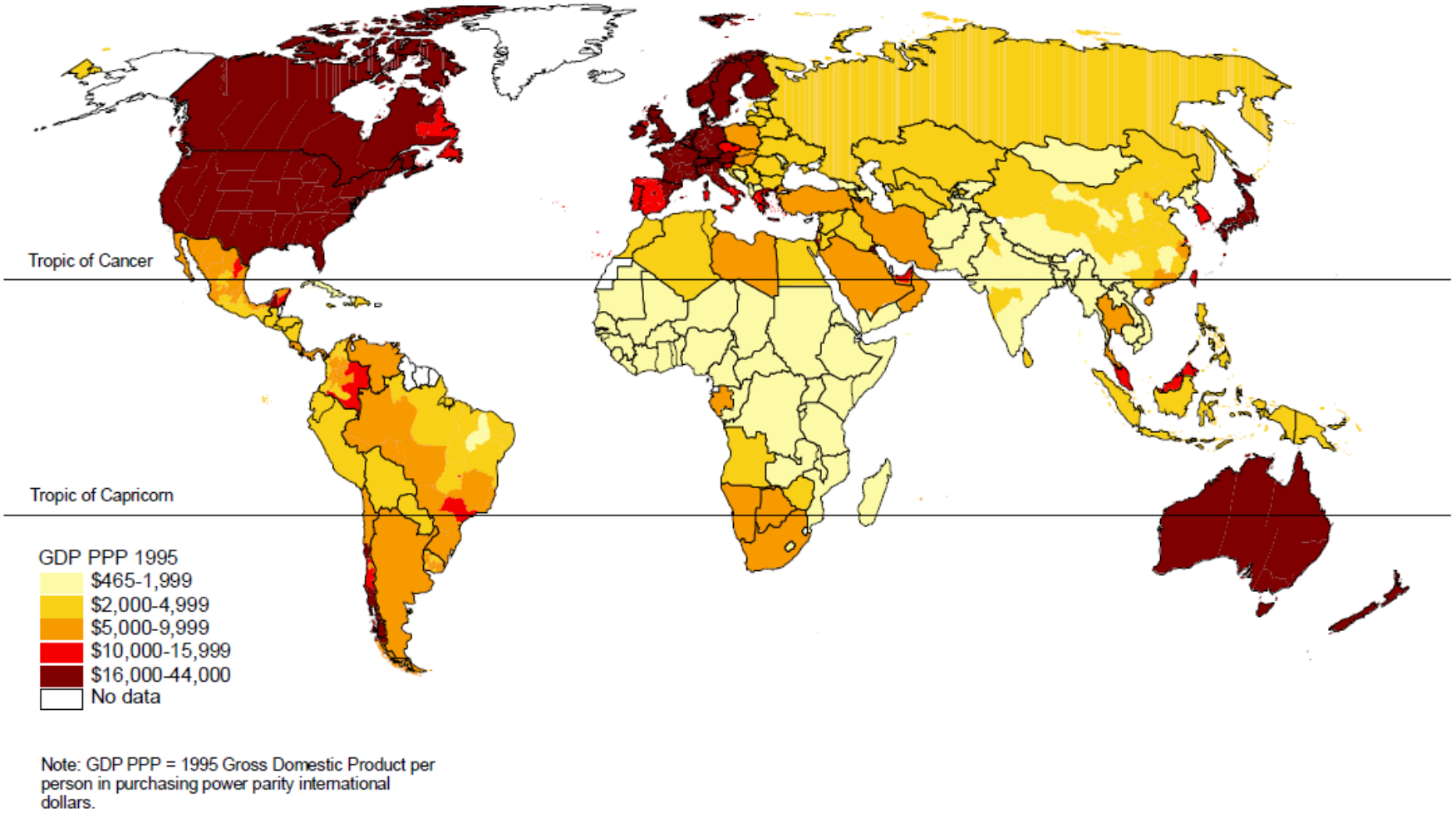
Source: Jones and Vollrath, *Economic Growth,* and Penn World Tables.

Contribution of Technology

$$\frac{Y^*}{POP} = f\left(\frac{K^*}{N^*}, T\right) \bullet \frac{N^*}{POP}$$

- The types of technology that vary across countries are probably not knowledge, but institutions and culture
- And this variation is an important source of the variation in normal output per capita.

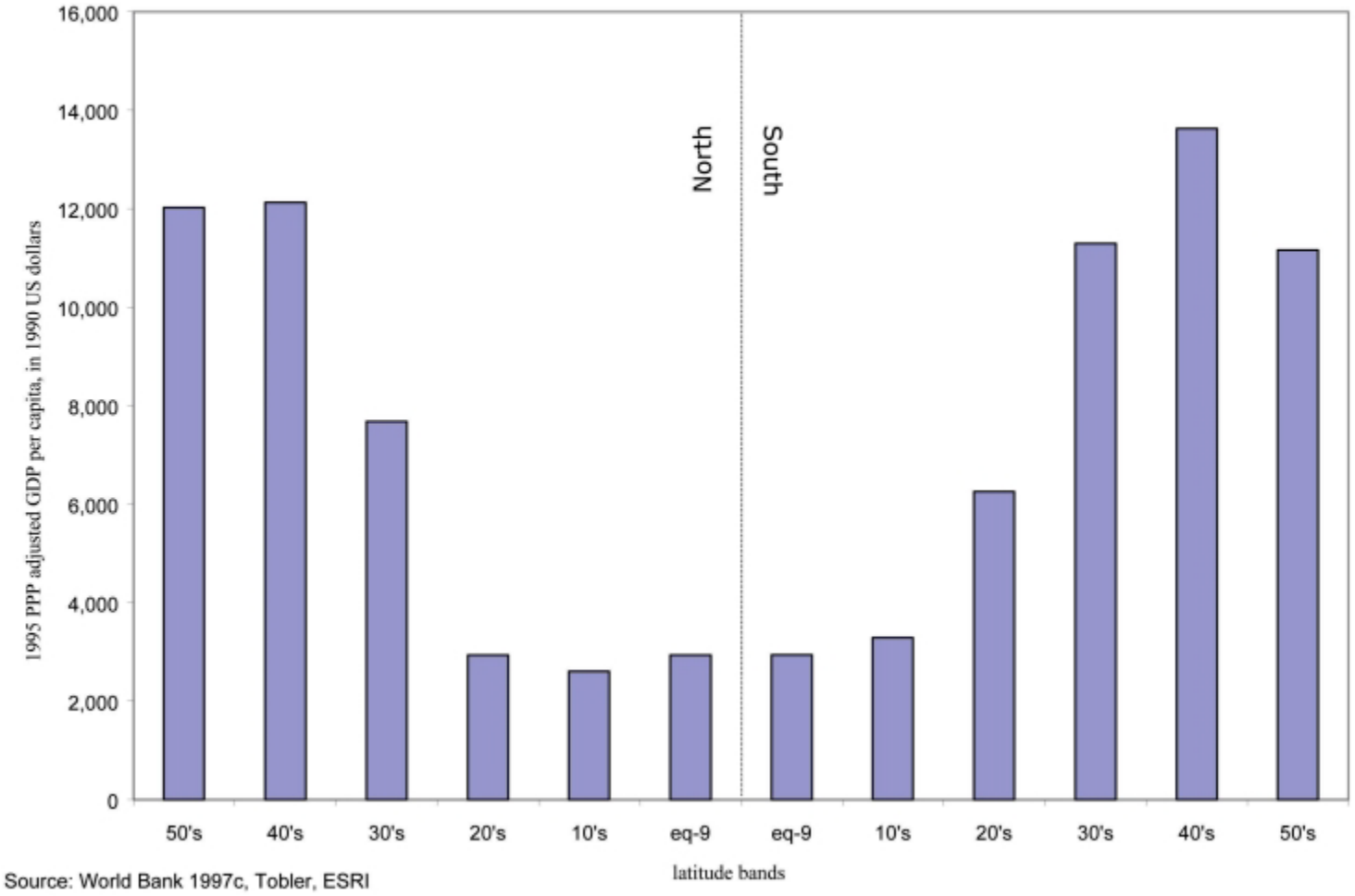
Figure 1. Income per person, 1995 (with sub-national data for 19 countries)



Note: GDP PPP = 1995 Gross Domestic Product per person in purchasing power parity international dollars.

Source: Gallup and Sachs, "The Economic Burden of Malaria."

Figure 2. GDP per capita by Latitude

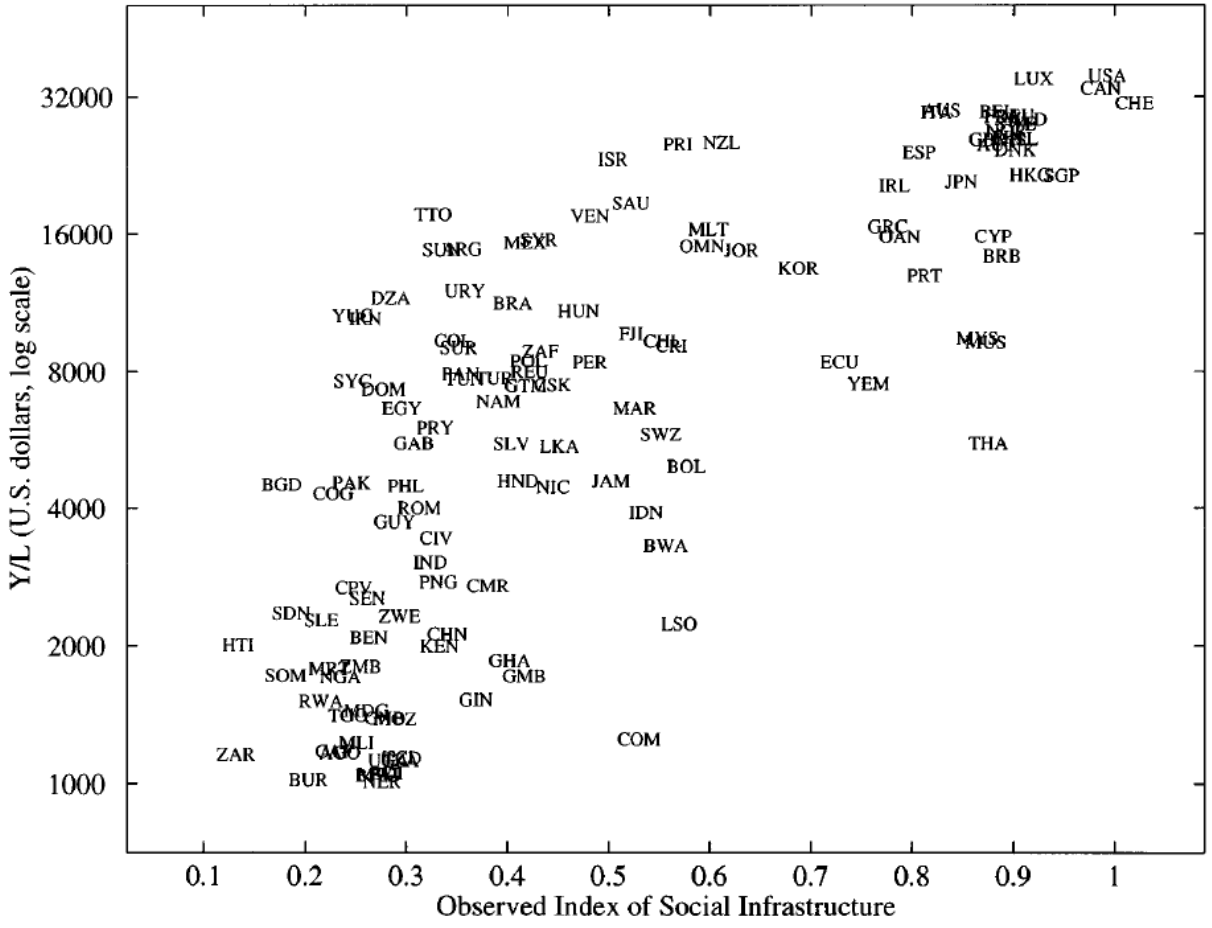


Source: Gallup and Sachs, "The Economic Burden of Malaria."

Three Key Features of Institutions that Contribute to High Normal Output per Person

- A market-based system for allocating resources.
- Government protection of property from others.
- Protection of property from government corruption, theft, arbitrary taxation, ….

Average Labor Productivity and Social Infrastructure



Source: Hall and Jones, “Why Do Some Countries Produce So Much More Output per Worker than Others?”

V. Determinants of Economic Growth

Aggregate Production Function

(1) $$\frac{Y^*}{POP} = \frac{Y^*}{N^*} \bullet \frac{N^*}{POP}$$

(2) $$\frac{Y^*}{N^*} = f\left(\frac{K^*}{N^*}, T\right)$$

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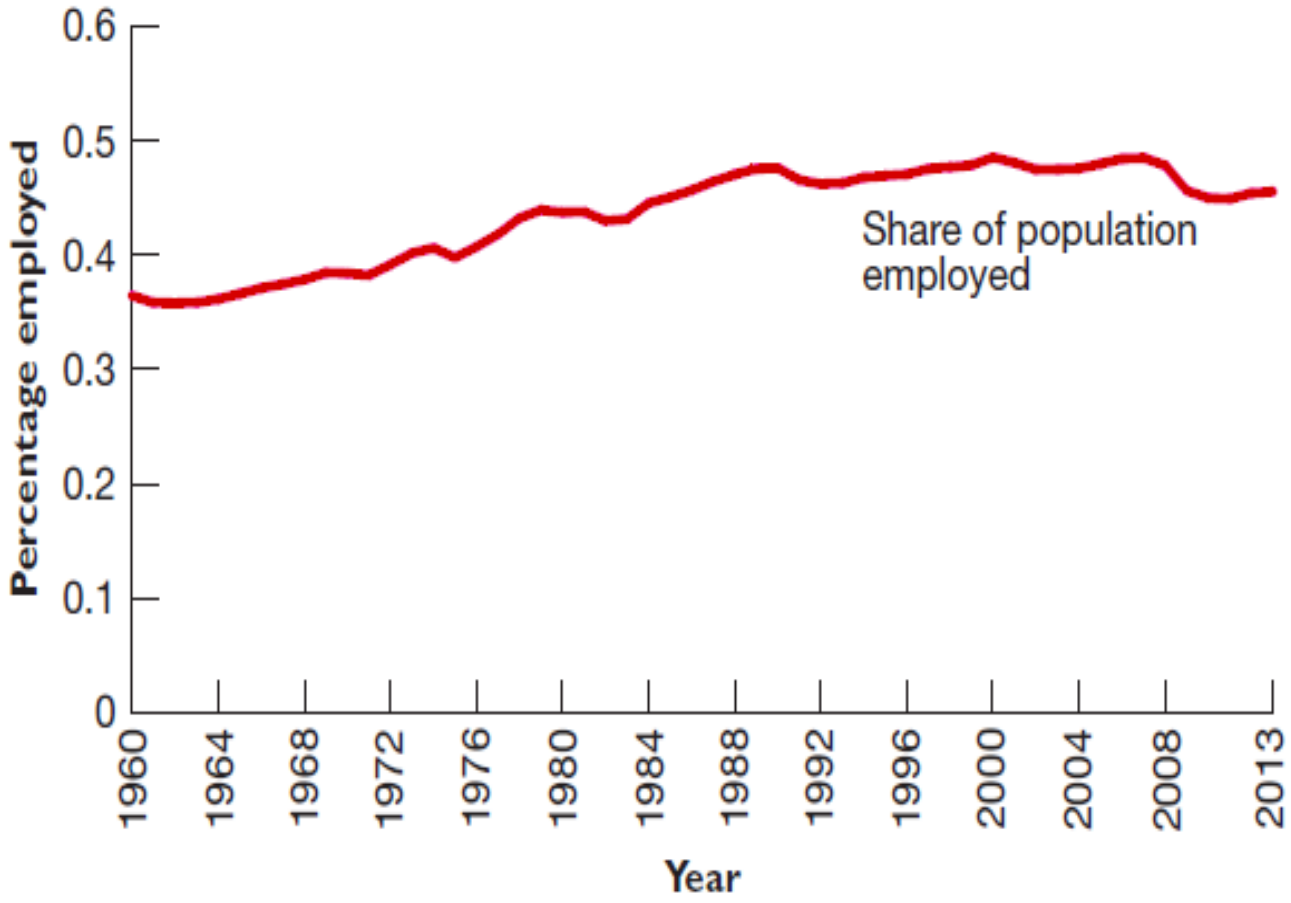
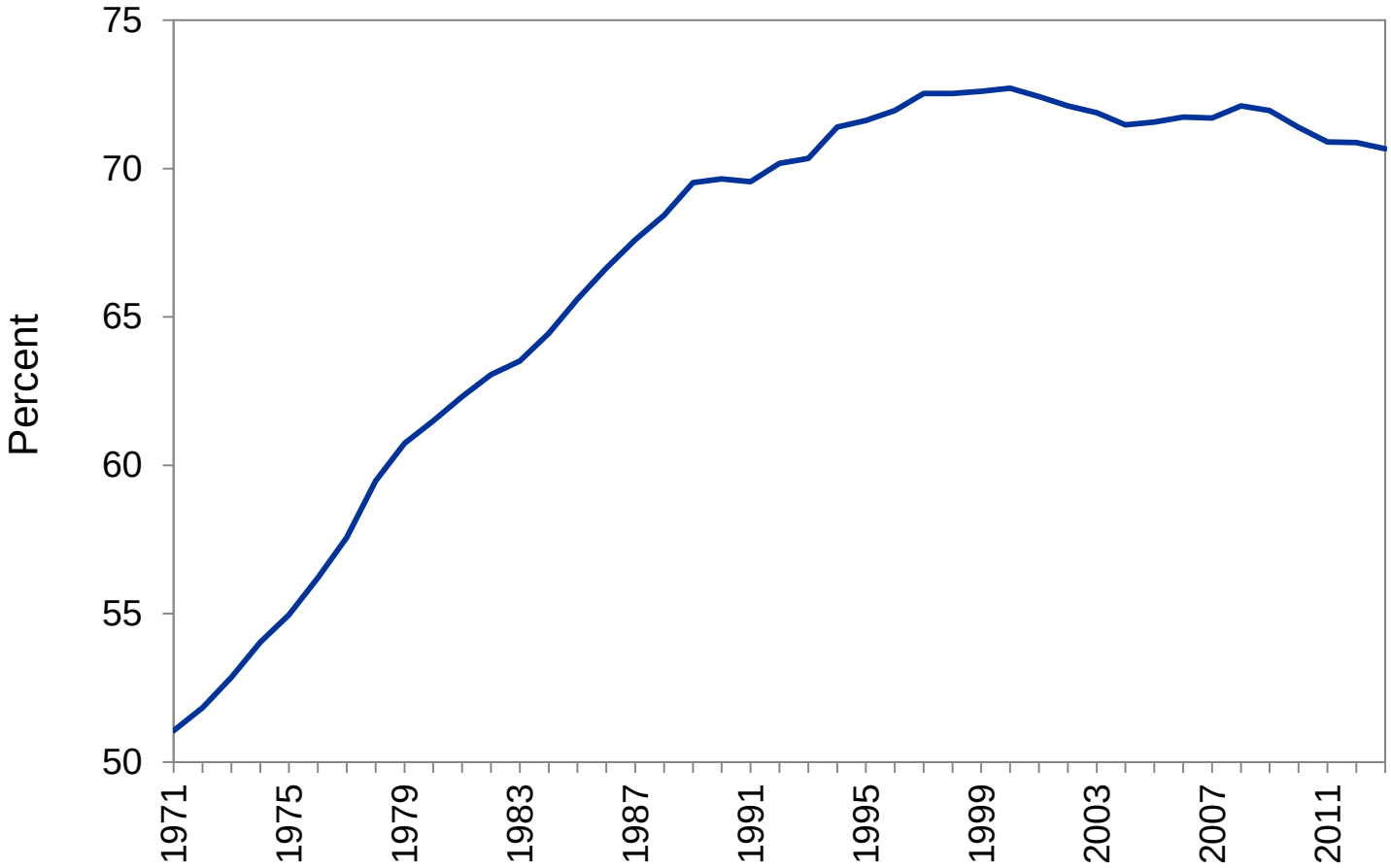
Employment-to-Population Ratio in the U.S.



Source: Frank, Bernanke, Antonovics, and Heffetz, *Principles of Economics*.

Labor Force Participation Rate for Women in the U.S.



Source: Bureau of Labor Statistics

Can Increases in N*/POP Explain Growth?

- An increase in N*/POP will raise Y*/POP, and there have been periods when rises in N*/POP were important to growth.

- But, N*/POP doesn't tend to change much, can't rise indefinitely, and its contribution is limited by diminishing returns.

Aggregate Production Function

(1) $$\frac{Y^*}{POP} = \frac{Y^*}{N^*} \bullet \frac{N^*}{POP}$$

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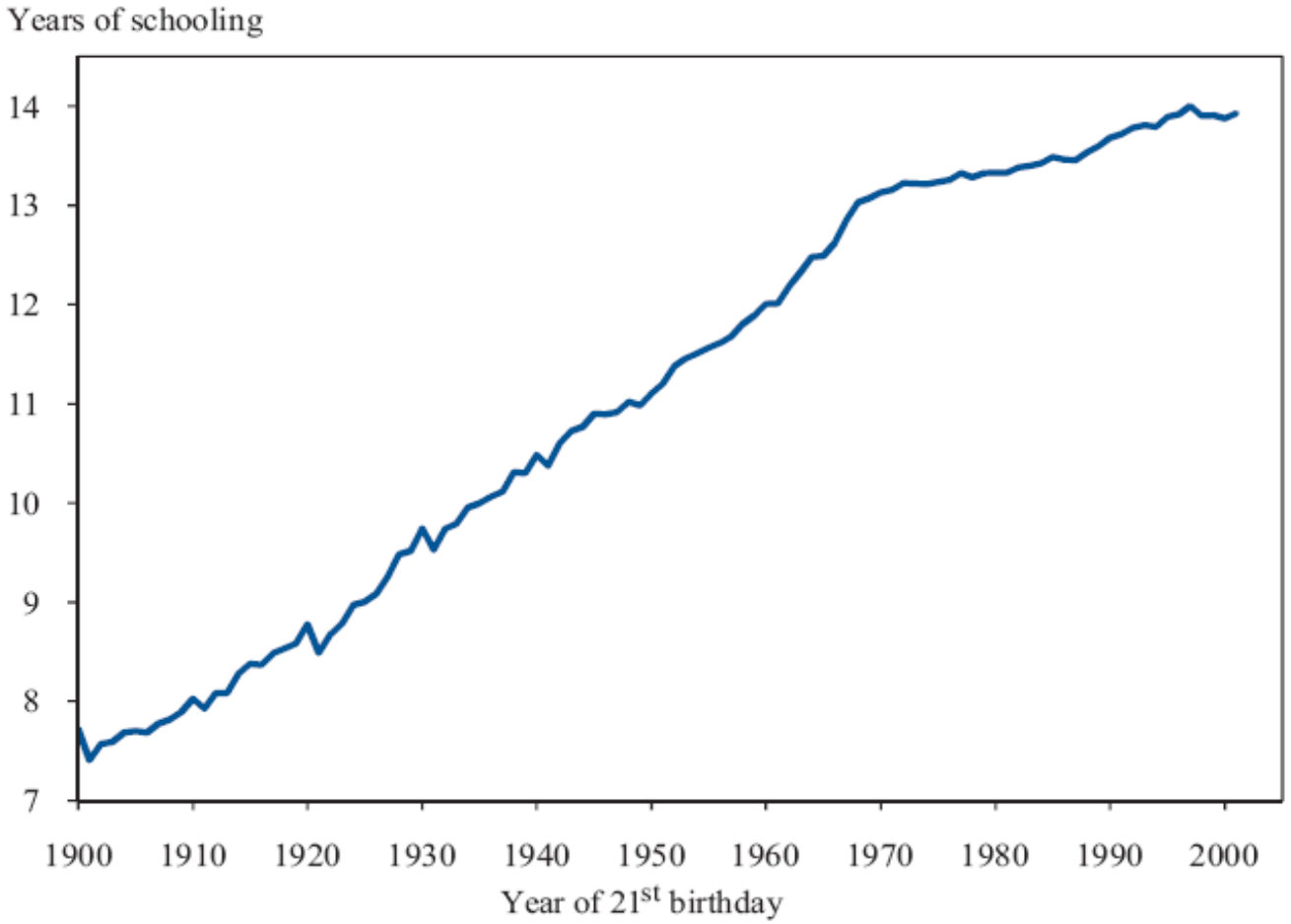
Can Increases in K*/N* Explain Growth?

- An increase in K*/N* will raise Y*/POP, and there have been periods when capital accumulation was important to growth.
- But, diminishing returns means that doubling K*/N* less than doubles Y*/POP.
- Observed increases in K*/N* are not large enough to account for much of the observed rise in Y*/POP over time.

Can Increases in Human Capital Explain Growth?

- Human capital has increased substantially over the past 100+ years.
- The increases probably account for a moderate amount of the observed rise in Y*/POP over time.

Figure 1-7
Mean Years of Schooling by Birth Cohort



Notes: Years of schooling at 30 years of age. Methodology described in Goldin and Katz (2007).
Sources: Department of Commerce (Bureau of the Census), 1940-2000 Census IPUMS, 2005 CPS MORG; Goldin and Katz (2007).

Source: *Economic Report of the President* 2010.

Technological change is a key determinant of economic growth

$$\frac{Y^*}{POP} = f\left(\frac{K^*}{N^*}, T\right) \bullet \frac{N^*}{POP}$$

- Argument by elimination: If it is not N*/POP or K*/N*, it must be T.

VI. Historical Evidence of Technological Change

New Production Techniques

- New machines (electric motor, tractor).
- New methods of organization and management (assembly line, accounting).

Early Textile Mill

Modern Textile Factory

Social Savings from the Farm Tractor in 1954

(All values in millions of dollars)

Source	1954 Crop Mix	1909 Crop Mix
Wage labor freed up	27,800	29,800
Land reallocated	200	200
Exports maintained	1,000	1,000
Crop inventory increased	600	600
Less: Fuels used	(400)	(400)
Total savings	29,200	31,200
1954 U.S. GNP	364,800	364,800
Savings as % of GNP	8.0 %	8.6 %

Source: Steckel and White, "Engines of Growth."

New Products

- Another way to create improvements in the standard of living.

Table 1.7 Treatment of the Great Inventions

Invention	Treatment in Price Indexes
Aeronautics, helicopter	Except for lower costs of transportation of intermediate goods, lower prices not reflected in price indexes
Air-conditioning	Outside of refrigerated transportation and productivity increases in the workplace, amenities and health effects not captured in price indexes
Continuous casting of steel	A process innovation that showed up primarily in lower costs of intermediate goods and thus was reflected in price indexes of final goods
DDT and pesticides	Some (now questionable) benefits probably included in higher yields in agriculture and therefore included in price indexes; health benefits and ecological damages largely excluded from price indexes
Diesel-electric railway traction	A process innovation that showed up primarily in the price of goods and services
Insulin, penicillin, streptomycin	Improved health status not captured in price index
Internal combustion engine	Except for lower costs of transportation of intermediate goods, lower prices not reflected in price indexes
Long-playing record, radio, television	Major product inventions that are completely omitted from price indexes
Photo-lithography	Largely reflected in reduced printing costs
Radar	A wide variety of improvements, some of which might have shown up in lower business costs and prices (such as lower transportation costs or improved weather forecasting)
Rockets	A wide variety of implications: major application in telecommunications showed up in consumer prices; improvements in television not captured in price indexes; improved military technology and nuclear-war risk not reflected in prices
Steam locomotive	Reduced transportation costs of businesses reflected in price indexes; expansion of consumer services and nonbusiness uses not reflected
Telegraph, telephone	Improvements over Pony Express or mail largely unreflected in price indexes
Transistor, electronic digital computer	As key inventions of the electronic age, impacts outside business costs largely omitted in price indexes
Xerography	Major process improvement: some impact showed up in reduced clerical costs; expansion of use of copied materials not captured in price index
Zipper	Convenience over buttons omitted from price indexes

Better Institutions

- Example: Opening up to trade.
- Example: More reliance on market forces.