Economics 2 | Professor Christina Romer
Spring 2020 | Professor David Romer

LECTURE 16

TECHNOLOGICAL CHANGE AND ECONOMIC GROWTH

March 17, 2020

I. POTENTIAL OUTPUT AND LONG-RUN ECONOMIC GROWTH
   A. The critical importance of potential output to long-run outcomes
   B. The enormous variation in potential output per person across countries and over time
   C. The long-run consequences of small differences in growth rates
   D. Discussion of the paper by William Nordhaus
   E. Review of our aggregate production function framework

II. 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 of technology—especially institutions

III. EXPLAINING THE GROWTH IN Y*/POP OVER TIME
   A. Limited contribution of N*/POP
   B. Important, but limited contribution of K*/N*
   C. Crucial role of technological change

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

V. SOURCES OF TECHNOLOGICAL PROGRESS
   A. Factors that affect technological progress
   B. Does the market produce the efficient amount of invention?
   C. Policies to encourage technological progress

Economics 2
Spring 2020

Christina Romer
David Romer

Lecture 16

Technological Change and Economic Growth

March 17, 2020

Announcements

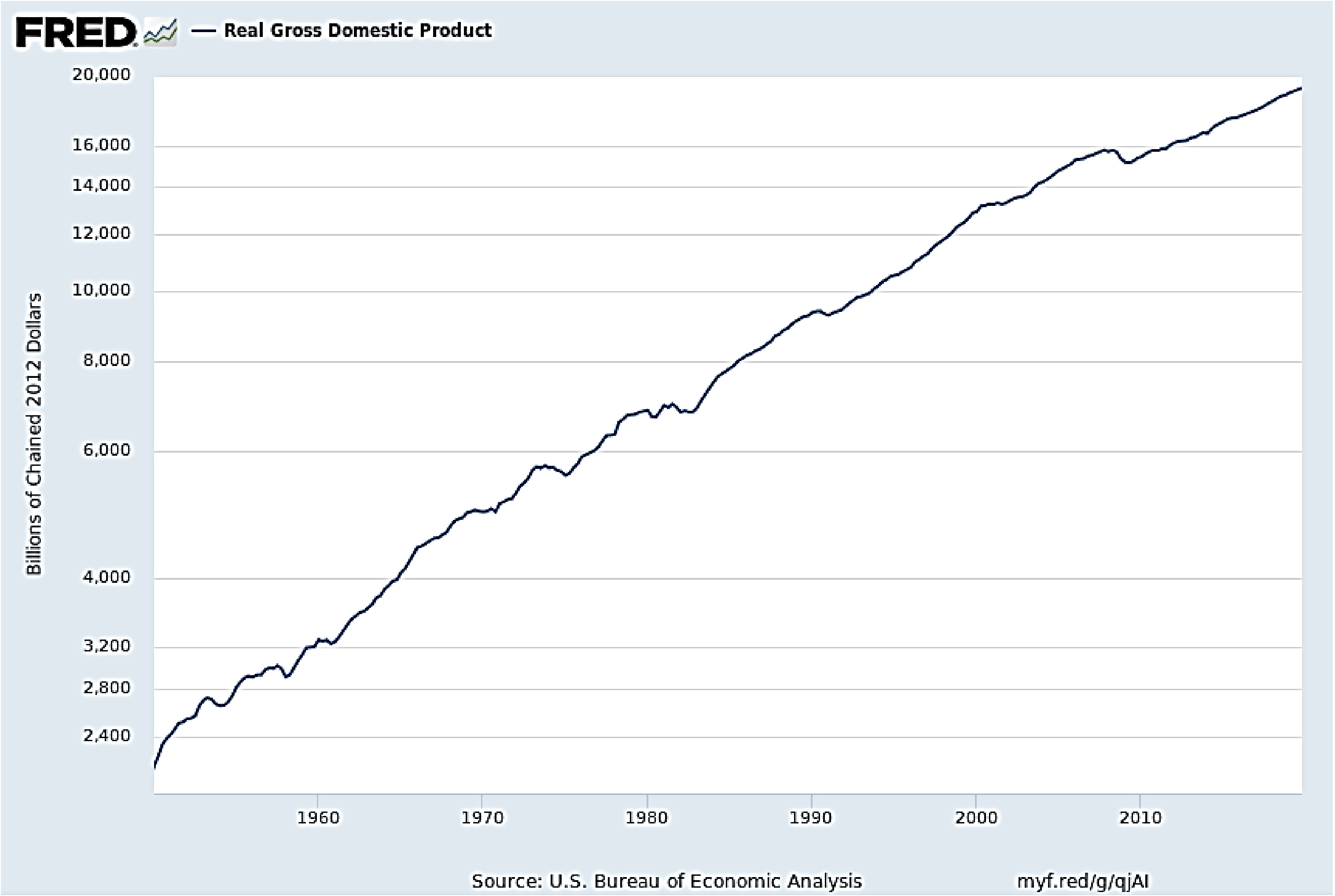
- Problem Set 4, Part 1 is due now.
    - If you were not able to complete it on time, please contact your GSI.
- Problem Set 4, Part 2 will be posted after lecture today.
    - It is due Tuesday, March 31, at 2 P.M.
    - The ground rules are the same as on previous problem sets.

Announcements

- Research reading for Thursday, March 19 (by Claudia Goldin and Lawrence Katz):
  - Read only the assigned pages.
  - Read for approach and findings.
- Professor office hours this week:
  - Our usual office hours: W, 1–3 P.M.
  - Extra meeting to discuss economic issues related to coronavirus: Th, starting at 4 P.M.

I. Potential Output and Long-Run Growth

Real GDP in the United States, 1950–2019



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

The Critical Importance of Potential Output to Long-Run Outcomes

- In the short run (in recessions and booms), the economy's use of its available resources can be above or below normal; this is central to short-run fluctuations.
- In the long run, output is determined by the economy's available resources.
- We call the amount of output the economy produces when using its resources at normal rates "potential output" (or "normal output"), denoted Y^*.

Variation in Potential Output per Person

- Differs enormously across countries.
- In many (but not all) countries, it has grown enormously over time.

Issues Relating to Potential Output

- The ***level*** of potential output per person.
  - This is an indicator of standards of living.
  - It differs enormously across countries.
  - What are the reasons for this variation?
- The ***growth rate*** of potential output per person over time.
  - In many (but not all) countries, it has grown enormously over time.
  - Over time, small differences in normal growth can have large impacts on standards of living.

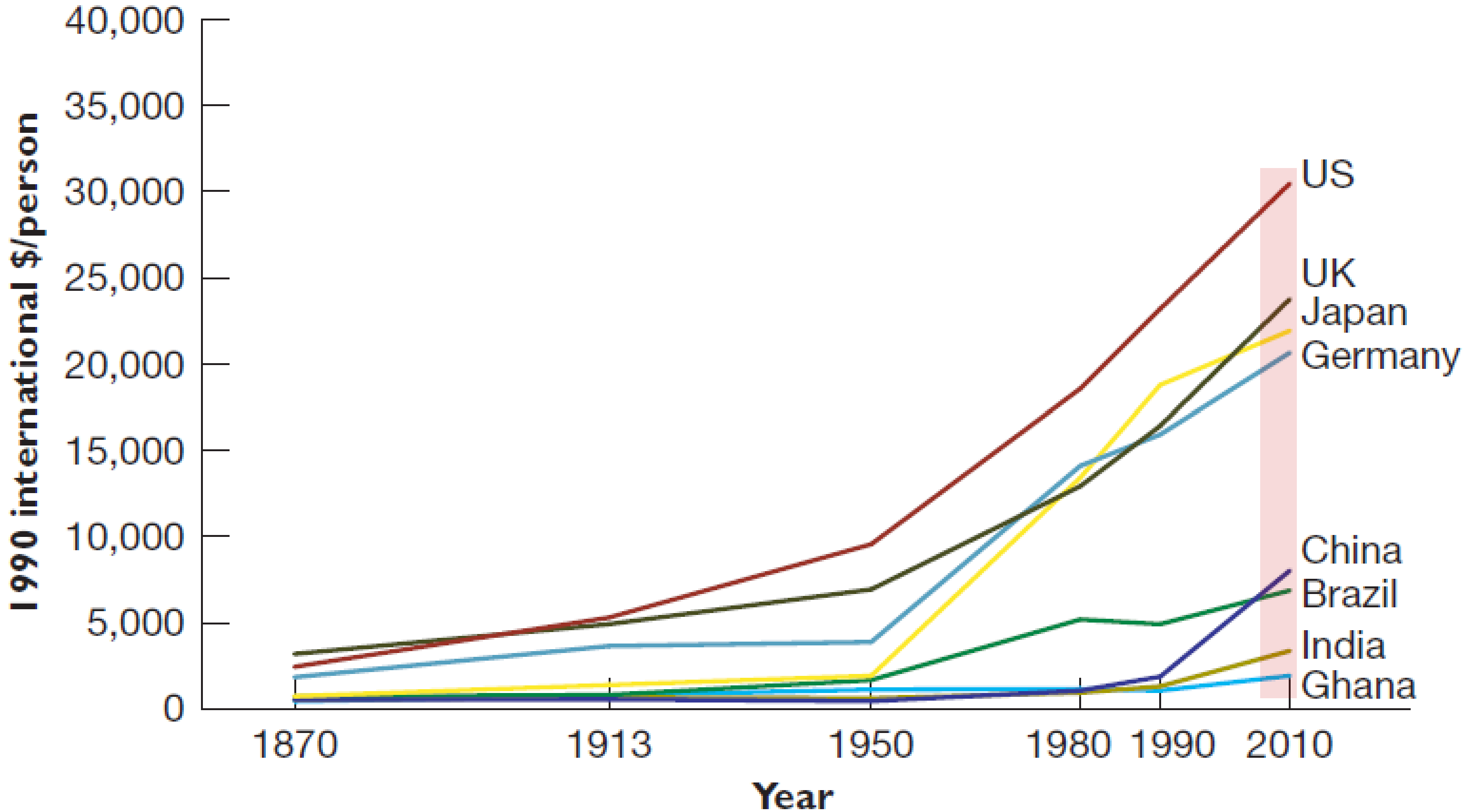
The Long-Run Consequences of Small Differences in Growth Rates

- Suppose countries A and B start with the same real income per capita.
- But annual growth in real income per capita is 1 percentage point higher in A than in B (for example, 1% vs. 0, or 2% vs. 1%).

Real Income per Capita in Country A Relative to Country B

- After 1 year: It is 1% higher.
- After 2 years: It is slightly more than 2% higher (1.01•1.01 = 1.0201. So it is 2.01% higher.)
- After 70 years: It is twice as high ($1.01^{70} \approx 2$).
- After 2 centuries: It is more than 7 times higher ($1.01^{200} \approx 7.3$).

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.

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

Paper by William Nordhaus

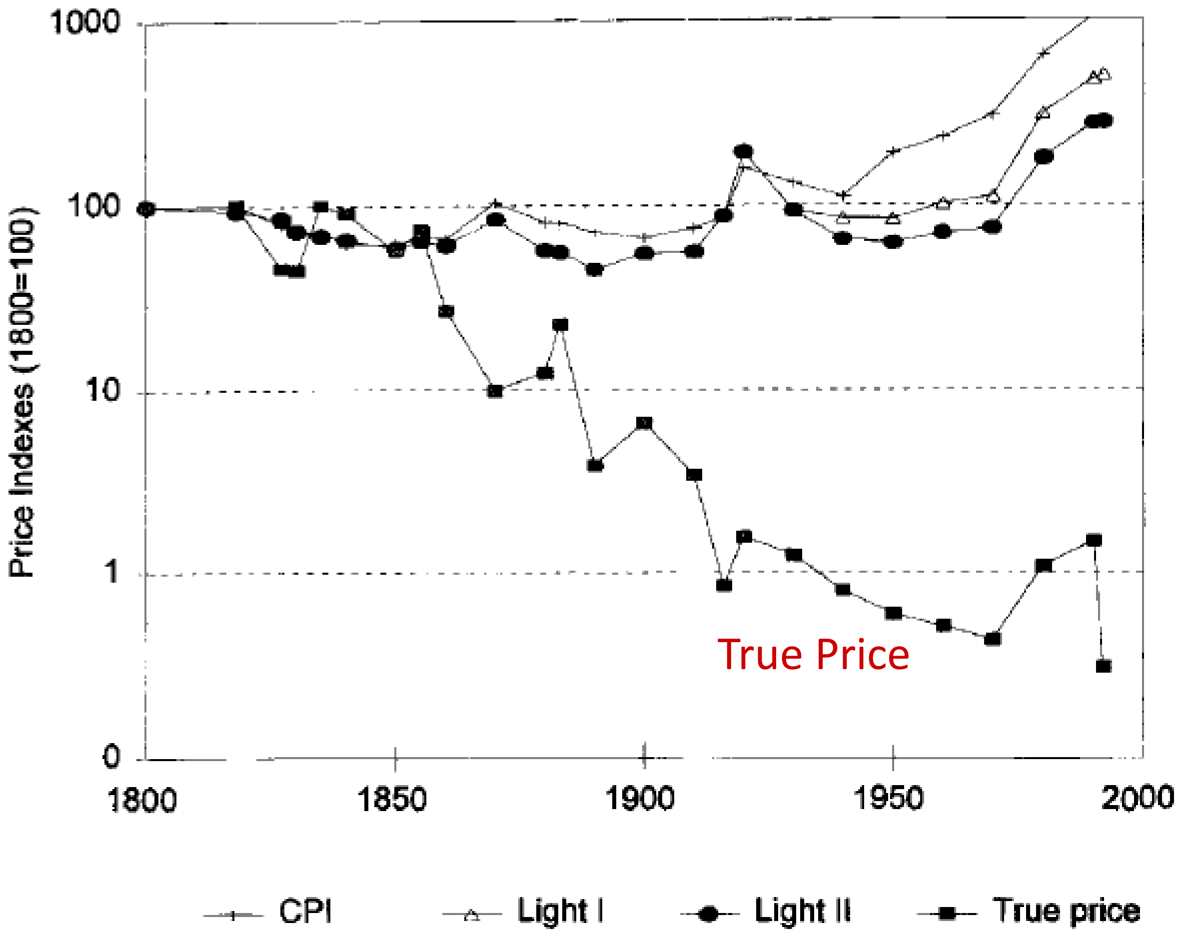
- What problems does Nordhaus see with typical price measures?
    - There may be quality changes.
    - New goods are being introduced all the time.
- What example does he use to illustrate the likely importance of these problems?
    - Lighting.

Table 1.3 **Efficiency of Different Lighting Technologies**

			Lighting Efficiency	
Device	Stage of Technology	Approximate Date	(lumens per watt)	(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[c]	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[c]	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?”

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?

Review of Our Aggregate Production Function Framework

- The Three Key Determinants of Potential Output:
  - Labor
  - Capital
  - Technology

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.

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.

Aggregate Production Function

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

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

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

What This Is Saying in Words

- Normal output per person is the product of the normal employment-to-population ratio and normal output per worker.
  - One implication: For a given level of normal output per worker, normal output per person is proportional to the normal employment-to-population ratio.
- Normal output per worker depends on two main things:
  - Normal capital per worker.
  - Technology.

II. 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.

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
France	31,980	69,910	0.46	2.2	30
United Kingdom	35,345	70,008	0.51	1.9	36
Spain	28,958	57,786	0.50	2.7	26
"Poor" countries					
China	6,415	10,938	0.59	5.6	13
India	3,078	7,801	0.39	3.0	24
Nigeria	1,963	6,106	0.32	0.6	114
Uganda	1,122	2,604	0.43	1.3	52
"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
South Korea	25,539	50,988	0.50	4.5	16
"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*.

Contribution of Capital per Worker

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

- Physical and human capital does vary a lot 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

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

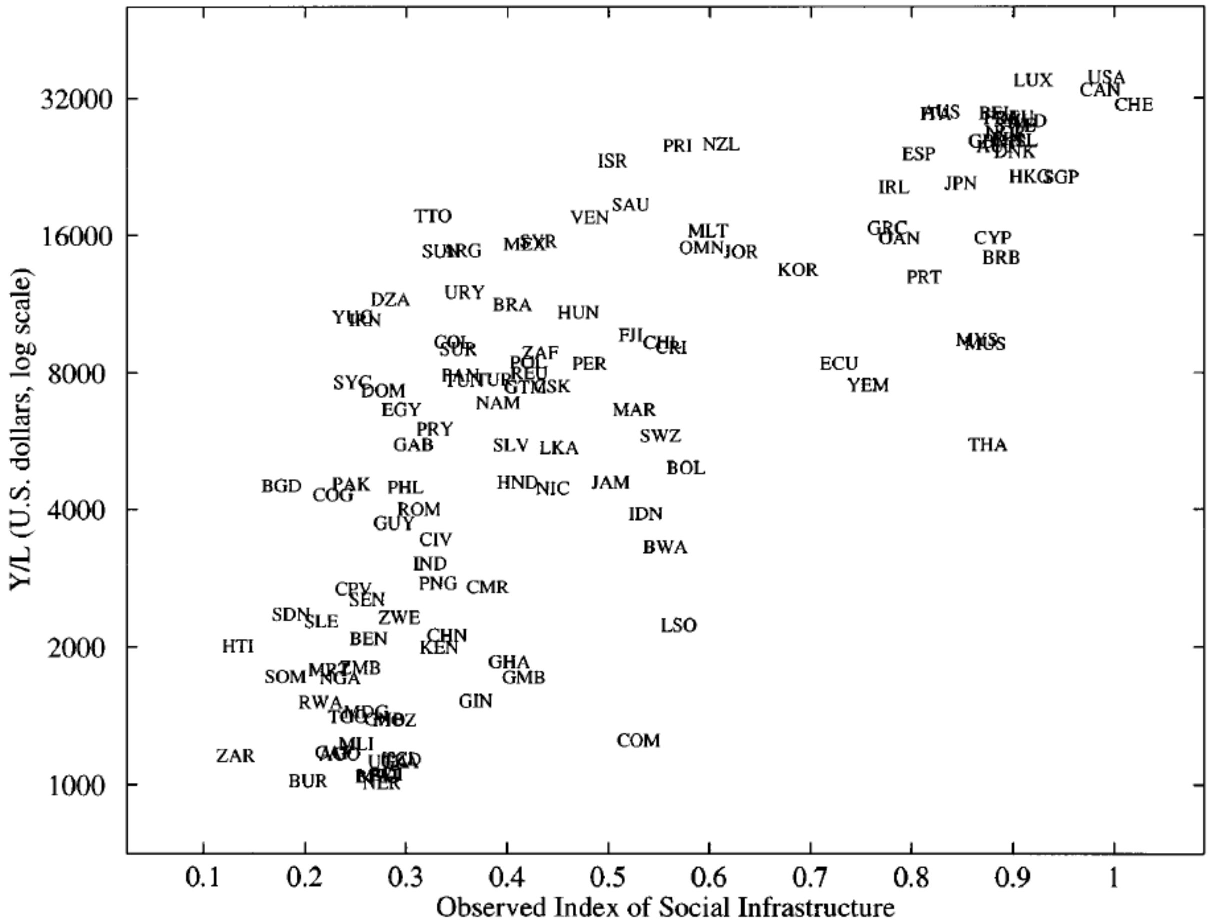
- The types of technology that vary significantly across countries are probably not knowledge, but institutions and culture.

- And this variation is an important source of the variation in normal output per capita.

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?"

Messages about Cross-Country Income Differences

- Differences in the normal employment-to-population ratio are not very important.
- Variations in normal capital per worker (both physical and human) and in technology are both very important.
- The most important type of variation in technology is not variation in knowledge or know-how, but variation in institutions.

III. Explaining the Growth in Potential Output per Person over Time

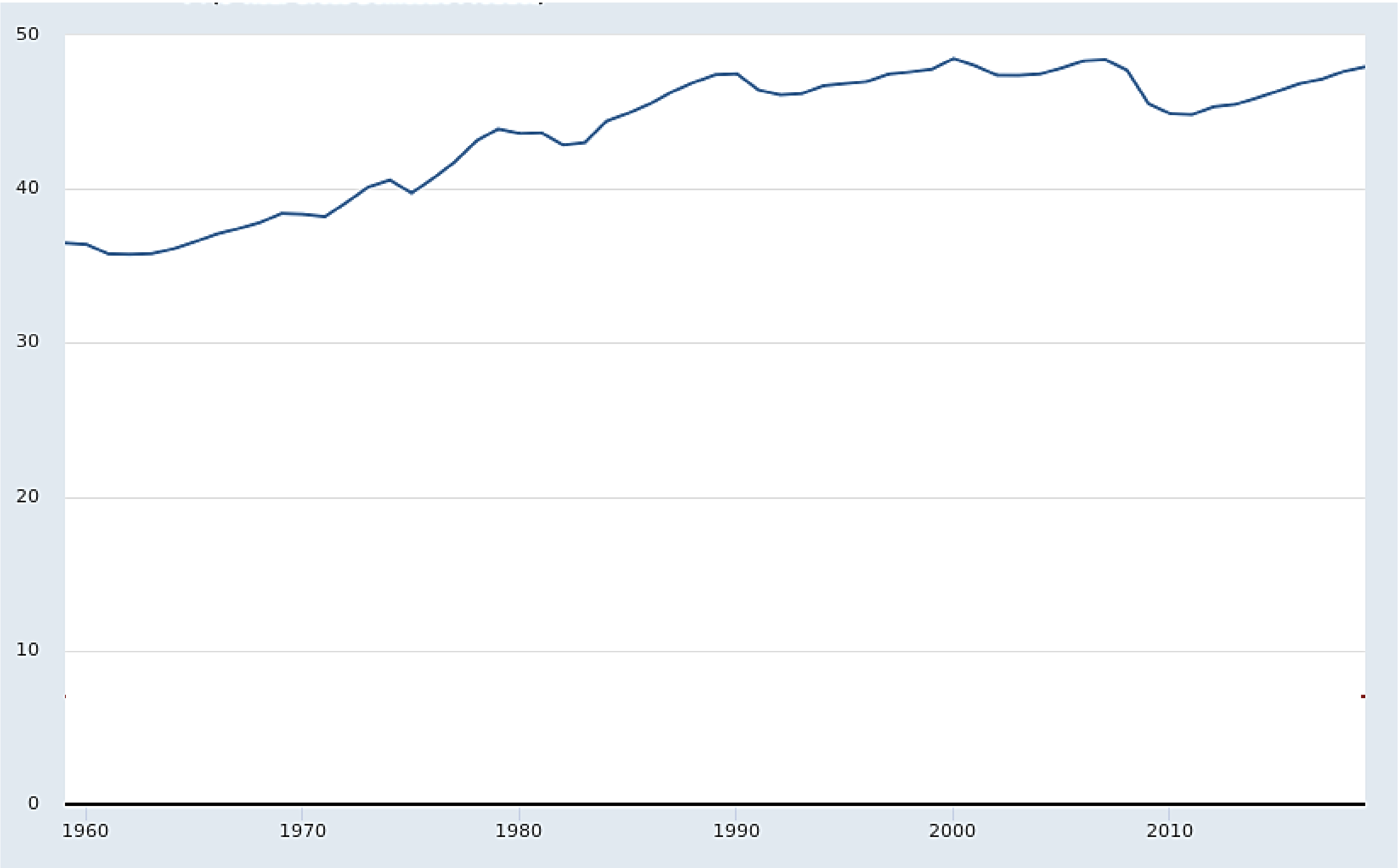
Aggregate Production Function

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

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

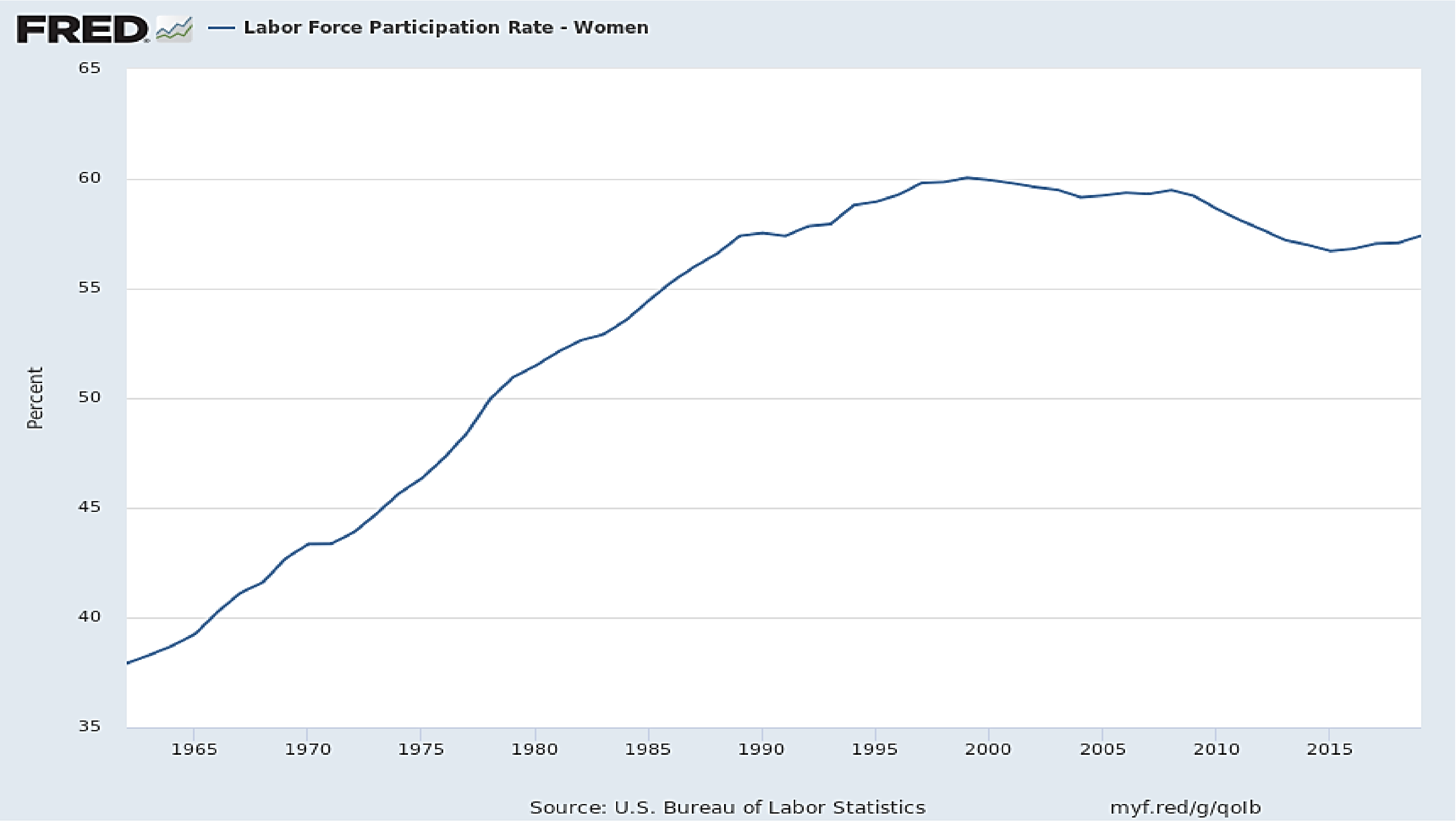
(3) $$\frac{Y^*}{POP} = f\left(\frac{K^*}{N^*}, T\right) \bullet \frac{N^*}{POP}$$

Employment-to-Population Ratio in the U.S. (percent)



Source: FRED; data from Bureau of Labor Statistics.

Labor Force Participation Rate, Women Ages 16+, United States, 1962–2019



Source: FRED; data from 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 had a noticeable impact on growth.
- But, N*/POP doesn't tend to change much, and it can't rise indefinitely.
- And its contribution is limited by diminishing returns:

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

When N*/POP rises, K*/N* tends to fall, and so Y*/POP rises less than proportionally with N*/POP.

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

Can Increases in K*/N* Explain Growth? The Case of Physical Capital

- 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.

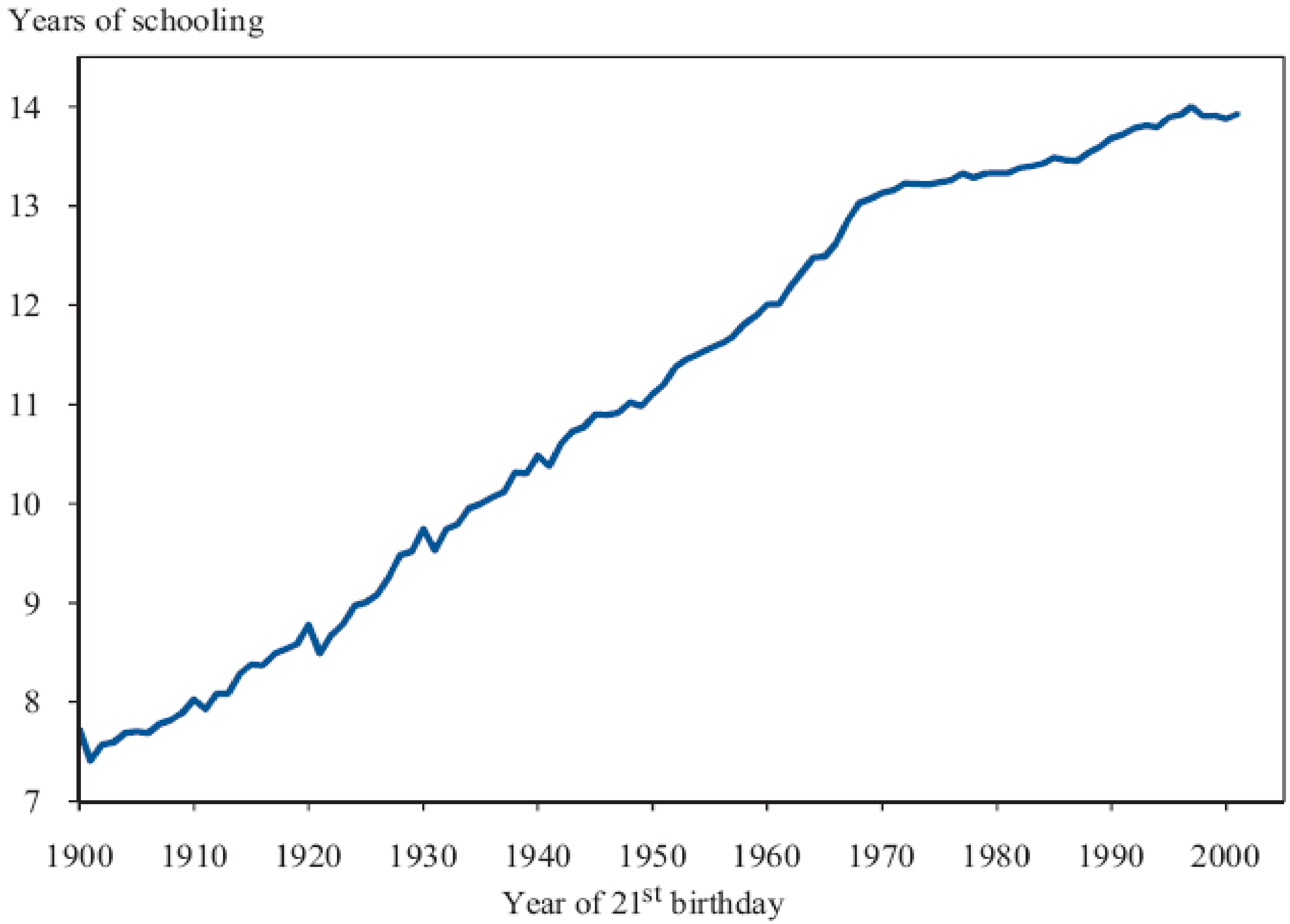
- Observed increases in K*/N* are not large enough to account for much of the observed rise in Y*/POP over time.

Can Increases in K*/N* Explain Growth? The Case of Human Capital

- 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

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

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

Messages about Economic Growth

- Changes in the normal employment-to-population ratio are not very important.
- Increases in normal capital per worker (both physical and human) are somewhat important.
- Improvements in technology are crucial.

IV. 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.

V. Sources of Technological Progress

[Note: This material will be covered at the start of Lecture 17.]