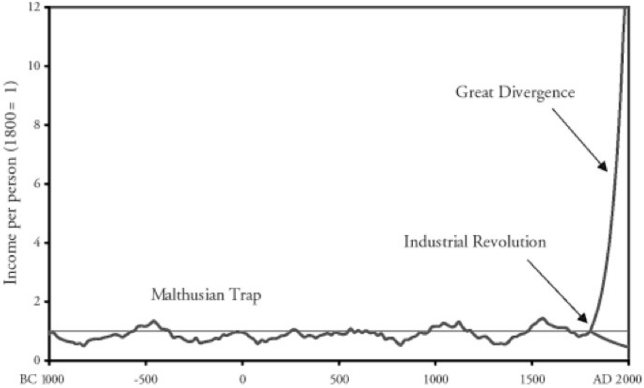
Readings for the Next Lectures

- Clark, Gregory (2008), *A Farewell to Alms*, excerpt from Chapter 3
- Steckel, Richard (2008), "Biological Measures of the Standard of Living", *Journal of Economic Perspectives*
- Bocquet-Appel, Jean-Pierre (2011), "When the World's Population Took Off", *Science*

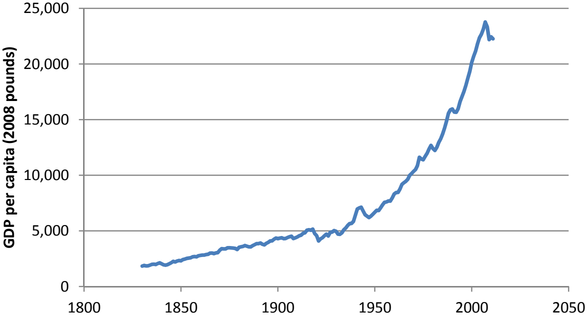
Economic Growth Throughout History



Measuring modern economic growth:

U.S. BUREAU OF LABOR STATISTICS

Economic Growth Throughout History



British real GDP per capita, 1830-2011

Measuring sort of modern economic growth:

Economic Growth Throughout History

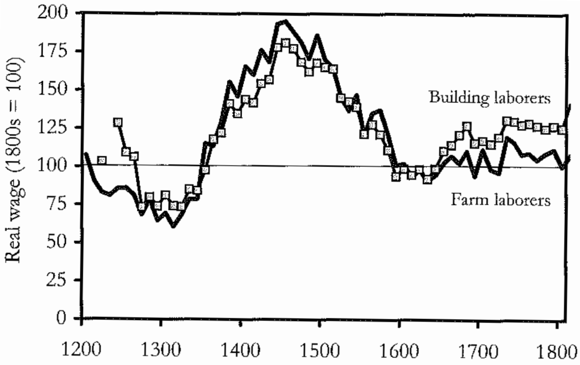


Figure 3.1 English laborers' real wages, 1209–1809.

Economic Growth Throughout History

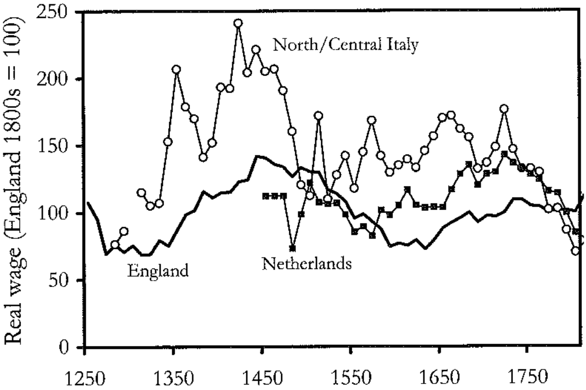


Figure 3.3 Comparative European real wages, 1250–1809. Northern and central Italian wages are from Federico and Malanima, 2004, appendix. Dutch wages are from de Vries and van der Woude, 1997, 609–28. The relative level of these wages to those in England in 1800 was fixed by assuming wages were proportionate to real GDP per person in each country relative to England in 1910 and 1810 respectively.

From Federico and Malanima (2004):

> *This method needs series of prices and wages, which are simply not available before 1300. In this case, following the pioneering work by Wrigley, the urbanization rate may be used in order to estimate output per worker, albeit crudely. In fact, if:*

Economic Growth Throughout History

1. *agricultural consumption and agricultural production are equal;*
2. *agricultural per caput consumption is constant–i.e., it is not affected by any change in prices or income;*
3. *the ratio of total workforce to population is constant;*
4. *the proportion of non-agricultural workers in the rural population is constant;*
5. *the time allocation between agricultural and non-agricultural work for all workers is constant;*

Economic Growth Throughout History

aggregate agricultural output equals per caput consumption of agricultural goods multiplied by population (P), and agricultural employment equals the whole population minus the urban population and rural non-agricultural population (millers, smiths, tailor, servants, carters, and so on). Thus, output per worker (y) can be calculated as:

$$y = \frac{P}{P - P(Ur + Rna)} = \frac{1}{1 - (Ur + Rna)}$$

Economic Growth Throughout History

Measuring ancient economic growth:

Economic Growth Throughout History

Table 3.4 Laborers' Wages in Wheat Equivalents

Location	Period	Day wage (pounds of wheat)
Ancient Babylonia[a]	1800–1600 BC	15*
Assyria[b]	1500–1350 BC	10*
Neo-Babylonia[a]	900–400 BC	9*
Classical Athens[c]	408 BC	30
	328 BC	24
Roman Egypt[d]	c. AD 250	8*
England[e,f]	1780–1800	13
	1780–1800	11*

Sources: [a]Powell, 1990, 98; Farber, 1978, 50–51. [b]Zaccagnini, 1988, 48. [c]Jevons, 1895, 1896. [d]Rathbone, 1991, 156–58, 464–45. [e]Clark, 2005. [f]Clark, 2001b.
Note: * denotes farm wage.

Measuring ancient economic growth:

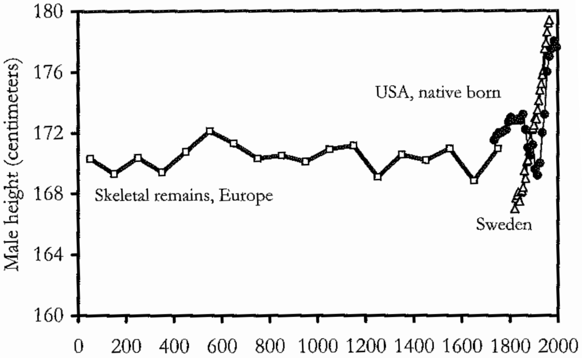
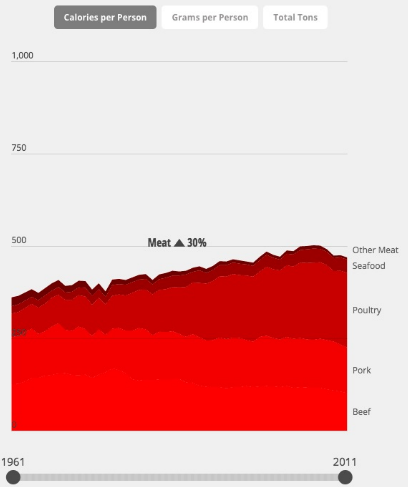


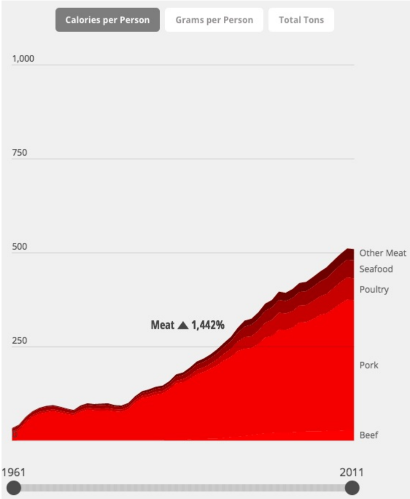
Figure 3.6 Male heights from skeletons in Europe, AD 1–2000. Data from Steckel, 2001, figures 3 and 4, and Koepke and Baten, 2005.

Economic Growth Throughout History



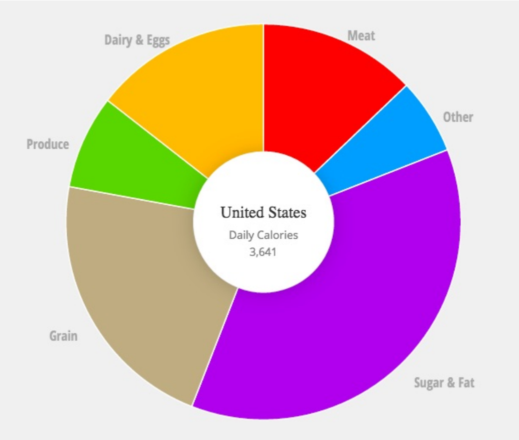
Meat consumption per person per day in the US (in calories)
http://www.nationalgeographic.com/what-the-world-eats/

Economic Growth Throughout History



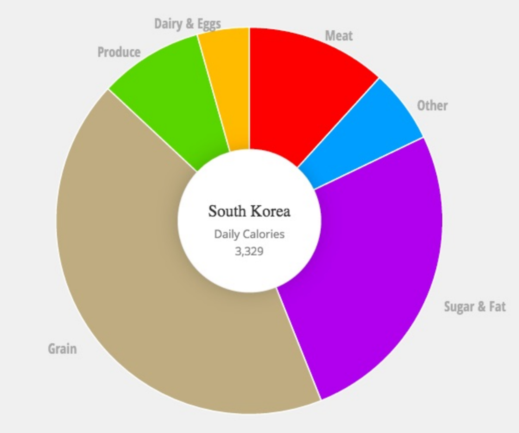
Meat consumption per person per day in China (in calories)
http://www.nationalgeographic.com/what-the-world-eats/

Economic Growth Throughout History

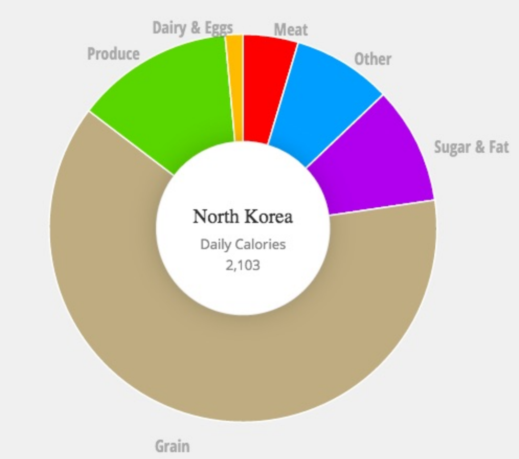


Average daily diet in the US
http://www.nationalgeographic.com/what-the-world-eats/

Economic Growth Throughout History



Average daily diet in the South Korea
http://www.nationalgeographic.com/what-the-world-eats/



Average daily diet in the North Korea
http://www.nationalgeographic.com/what-the-world-eats/

Economic Growth Throughout History

Table 3.7 Share of Different Products in Food Consumption of Farm Workers

Location	Period	Cereals and pulses (%)	Sugar (%)	Animal products, fats (%)	Alcohol (%)
England[a]	1250–99	48.0	0.0	40.2	11.8
	1300–49	39.7	0.0	43.0	17.0
	1350–99	20.8	0.0	55.3	24.0
	1400–49	18.3	0.0	46.4	34.3
England[b]	1787–96	60.6	4.7	28.4	1.3
Japan[c]	ca. 1750	95.4	0.0	4.6	0.0
India[d]	1950	83.3	1.6	5.4	0.8

Sources: [a]Dyer, 1988. [b]Clark et al., 1995. [c]Bassino and Ma, 2005. [d]Government of India, Ministry of Labour, 1954, 114, 118.

Growth Accounting

- Growth accounting is a process of breaking up growth in output into the portion due to growth in each input
- We typically assume that output is produced using capital (K), labor (L), land (Z) and some level of technology (A):

$$Y = AF(K, L, Z)$$

- Notice that technology improves the productivity of all inputs (it is sometimes called total factor productivity)

Growth Accounting

$$Y = AF(K, L, Z)$$

- If output gets larger, it has to be because A, K, L or Z got larger (or some combination of them)
- We want to figure out how much of the change in Y we see in modern economies is due to changes in A, changes in K, changes in L and changes in Z
- Knowing this will help us determine what drives modern economic growth and why we didn't get economic growth in the preindustrial world

Growth Accounting

- For any single factor, the change in output created by a change in that factor will be the change in the factor multiplied by the marginal product of that factor
- For example, suppose there is a change in capital (and nothing else), then the change in output will be:

$$\Delta Y = MP_K \cdot \Delta K$$

- As long as markets for inputs are competitive, the price of a unit of capital will be equal to its marginal product
- So we can substitute the rental rate of capital (r) for MP_K in the equation above:

$$\Delta Y = r \cdot \Delta K$$

Growth Accounting

- If all of the inputs are changing, they are all contributing to ΔY:

$$\Delta Y = \Delta A \cdot F(K, L, Z) + MP_K \cdot \Delta K + MP_L \cdot \Delta L + MP_Z \cdot \Delta Z$$

- Using the assumption that factor prices will equal their marginal products if markets are competitive:

$$\Delta Y = \Delta A \cdot F(K, L, Z) + r \cdot \Delta K + w \cdot \Delta L + s \cdot \Delta Z$$

- r is the rental rate of capital, w is the wage paid to a worker and s is the rental price for a unit of land
- Now it is just a few steps of algebra to get to our growth accounting equation

Growth Accounting

$$\Delta Y = \Delta A \cdot F(K, L, Z) + r \cdot \Delta K + w \cdot \Delta L + s \cdot \Delta Z$$

Growth Accounting

$$\Delta Y = \Delta A \cdot F(K, L, Z) + r \cdot \Delta K + w \cdot \Delta L + s \cdot \Delta Z$$

$$\Delta Y = \frac{A}{A}\Delta A \cdot F(K, L, Z) + \frac{K}{K}r \cdot \Delta K + \frac{L}{L}w \cdot \Delta L + \frac{Z}{Z}s \cdot \Delta Z$$

Growth Accounting

$$\Delta Y = \Delta A \cdot F(K, L, Z) + r \cdot \Delta K + w \cdot \Delta L + s \cdot \Delta Z$$

$$\Delta Y = \frac{A}{A}\Delta A \cdot F(K, L, Z) + \frac{K}{K} r \cdot \Delta K + \frac{L}{L} w \cdot \Delta L + \frac{Z}{Z} s \cdot \Delta Z$$

$$\frac{\Delta Y}{Y} = \frac{AF(K, L, Z)}{Y}\frac{\Delta A}{A} + \frac{rK}{Y}\frac{\Delta K}{K} + \frac{wL}{Y}\frac{\Delta L}{L} + \frac{sZ}{Y}\frac{\Delta Z}{Z}$$

Growth Accounting

$$\Delta Y = \Delta A \cdot F(K, L, Z) + r \cdot \Delta K + w \cdot \Delta L + s \cdot \Delta Z$$

$$\Delta Y = \frac{A}{A}\Delta A \cdot F(K, L, Z) + \frac{K}{K} r \cdot \Delta K + \frac{L}{L} w \cdot \Delta L + \frac{Z}{Z} s \cdot \Delta Z$$

$$\frac{\Delta Y}{Y} = \frac{AF(K, L, Z)}{Y}\frac{\Delta A}{A} + \frac{rK}{Y}\frac{\Delta K}{K} + \frac{wL}{Y}\frac{\Delta L}{L} + \frac{sZ}{Y}\frac{\Delta Z}{Z}$$

$$g_Y = g_A + \frac{rK}{Y} g_K + \frac{wL}{Y} g_L + \frac{sZ}{Y} g_Z$$

Growth Accounting

$$g_Y = g_A + \frac{rK}{Y}g_K + \frac{wL}{Y}g_L + \frac{sZ}{Y}g_Z$$

- The equation above relates the growth rate of output to the growth rates of all of our inputs
- The coefficients in front of each input represent the share of output paid to the owners of that particular input
- We'll call the share of output paid to capital owners a, the share of output paid to workers b and the share of output paid to landowners c
- Since capital, labor and land represent all of the places payments can go, $a + b + c$ must equal 1

Growth Accounting

$$g_Y = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z$$

- The equation above is our first growth accounting equation and is in terms of total output
- But if we want to measure changes in the standard of living, we need to measure changes in output per person
- It is actually fairly easy to convert the equation above into per capita terms
- There are two key things to remember:
  - $a + b + c = 1$
  - For any variable X, the growth rate of X per worker is the growth rate of X minus the growth rate of workers

Growth Accounting

More algebra:

Growth Accounting

More algebra:

$$g_Y = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z$$

Growth Accounting

More algebra:

$$g_Y = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z$$

$$g_Y - g_L = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z - (a + b + c)g_L$$

Growth Accounting

More algebra:

$$g_Y = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z$$

$$g_Y - g_L = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z - (a + b + c)g_L$$

$$g_Y - g_L = g_A + a(g_K - g_L) + b(g_L - g_L) + c(g_Z - g_L)$$

Growth Accounting

More algebra:

$$g_Y = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z$$

$$g_Y - g_L = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z - (a + b + c)g_L$$

$$g_Y - g_L = g_A + a(g_K - g_L) + b(g_L - g_L) + c(g_Z - g_L)$$

$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

Growth Accounting

- Now we have two ways to decompose economic growth:

$$g_Y = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z$$

$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

- Note that g_Z is usually zero (and therefore g_z is typically negative)
- g_L can be measured using population data
- g_Y and g_y can be measured using GDP statistics
- g_K and g_k can also be measured
- a, b and c are all measurable
- This leaves us with g_A, a 'measure of our ignorance' (but what we call technology)

Announcements

- Readings for the next lectures:
  - Clark, Gregory (2008), *A Farewell to Alms*, excerpt from Chapter 3
  - Steckel, Richard (2008), "Biological Measures of the Standard of Living", *Journal of Economic Perspectives*
  - Bocquet-Appel, Jean-Pierre (2011), "When the World's Population Took Off", *Science*
- We'll talk about the referee reports on Friday

Growth Accounting

$$Y = AF(K, L, Z)$$

- If output gets larger, it has to be because A, K, L or Z got larger (or some combination of them)
- We want to figure out how much of the change in Y we see in modern economies is due to changes in A, changes in K, changes in L and changes in Z
- Knowing this will help us determine what drives modern economic growth and why we didn't get economic growth in the preindustrial world

Growth Accounting

- Last class we derived two ways to decompose economic growth:

$$g_Y = g_A + a \cdot g_K + b \cdot g_L + c \cdot g_Z$$

$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

- Note that g_Z is usually zero (and therefore g_z is typically negative)
- g_L can be measured using population data
- g_Y and g_y can be measured using GDP statistics
- g_K and g_k can also be measured
- a, b and c are all measurable
- This leaves us with g_A, a 'measure of our ignorance' (but what we call technology)

Growth Accounting: An Example

For example, suppose a country has a population growing at 4% a year, a capital stock growing at 8% a year and output per capita growing at 5% a year. 25% of national income goes to the owners of capital and 70% goes to workers. What is the growth rate of technology?

Growth Accounting: An Example

For example, suppose a country has a population growing at 4% a year, a capital stock growing at 8% a year and output per capita growing at 5% a year. 25% of national income goes to the owners of capital and 70% goes to workers. What is the growth rate of technology?

$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

Growth Accounting: An Example

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$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

$$5 = g_A + .25 \cdot g_k + (1 - .25 - .7) \cdot g_z$$

Growth Accounting: An Example

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$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

$$5 = g_A + .25 \cdot g_k + (1 - .25 - .7) \cdot g_z$$

$$5 = g_A + .25(g_K - g_L) + .05(g_Z - g_L)$$

Growth Accounting: An Example

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$$5 = g_A + .25 \cdot g_k + (1 - .25 - .7) \cdot g_z$$

$$5 = g_A + .25(g_K - g_L) + .05(g_Z - g_L)$$

$$5 = g_A + .25(8 - 4) + .05(0 - 4)$$

Growth Accounting: An Example

For example, suppose a country has a population growing at 4% a year, a capital stock growing at 8% a year and output per capita growing at 5% a year. 25% of national income goes to the owners of capital and 70% goes to workers. What is the growth rate of technology?

$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

$$5 = g_A + .25 \cdot g_k + (1 - .25 - .7) \cdot g_z$$

$$5 = g_A + .25(g_K - g_L) + .05(g_Z - g_L)$$

$$5 = g_A + .25(8 - 4) + .05(0 - 4)$$

$$g_A = 4.2$$

Growth Accounting - Another Example

Suppose that output is growing at 5% a year, capital is growing at 5% a year, labor is growing at 1% a year and the shares of capital, labor and land in national output are .3, .6 and .1 respectively. What portion of the growth in output per person is due to growth in technology and what portion is due to growth in capital per worker?

Growth Accounting - Another Example

Suppose that output is growing at 5% a year, capital is growing at 5% a year, labor is growing at 1% a year and the shares of capital, labor and land in national output are .3, .6 and .1 respectively. What portion of the growth in output per person is due to growth in technology and what portion is due to growth in capital per worker?

- First, let's take a second to see what pieces of information we have been given:

$$g_Y = 5$$

$$g_K = 5$$

$$g_L = 1$$

$$a = .3, b = .6, c = .1$$

Growth Accounting - Another Example

Suppose that output is growing at 5% a year, capital is growing at 5% a year, labor is growing at 1% a year and the shares of capital, labor and land in national output are .3, .6 and .1 respectively. What portion of the growth in output per person is due to growth in technology and what portion is due to growth in capital per worker?

- We care about growth in output per person, so let's convert everything into per capita terms:

$$g_y = g_Y - g_L = 5 - 1 = 4$$

$$g_k = g_K - g_L = 5 - 1 = 4$$

$$g_z = g_Z - g_L = 0 - 1 = -1$$

Growth Accounting - Another Example

Suppose that output is growing at 5% a year, capital is growing at 5% a year, labor is growing at 1% a year and the shares of capital, labor and land in national output are .3, .6 and .1 respectively. What portion of the growth in output per person is due to growth in technology and what portion is due to growth in capital per worker?

- Now we can calculate g_A:

$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

$$4 = g_A + .3 \cdot 4 + .1 \cdot (-1)$$

$$g_A = 2.9$$

Growth Accounting - Another Example

Suppose that output is growing at 5% a year, capital is growing at 5% a year, labor is growing at 1% a year and the shares of capital, labor and land in national output are .3, .6 and .1 respectively. What portion of the growth in output per person is due to growth in technology and what portion is due to growth in capital per worker?

- Finally we can calculate the share of growth in y due to g_A and due to g_k:

$$\% \text{ due to } g_k = 100 \cdot \frac{a \cdot g_k}{g_y} = 100 \cdot \frac{.3 \cdot 4}{4} = 30$$

$$\% \text{ due to } g_A = 100 \cdot \frac{g_A}{g_y} = 100 \cdot \frac{2.9}{4} = 72.5$$

Growth Accounting

$$g_y = g_A + a \cdot g_k + c \cdot g_z$$

- How much the growth in capital, labor or land affects growth in output depends on the shares a, b and c
- a is typically around .25, b is typically around .7, c is typically around .05
- The bigger the part of our economy a particular factor of production is, the more its growth matters
- For A, a one percent increase in A leads to a one percent increase in both output and output per worker
- Population growth hurts us by making both g_k and g_z smaller

Growth Rates of Inputs and Output

Economic Growth, 1950-1980

Country	Growth rate (in %) of:			
	Y	K	L	Z
Britain	2.38	3.40	0.33	0.00
Germany	5.01	5.90	0.66	0.00
USA	3.18	3.85	1.26	0.00
Japan	7.77	8.00	1.10	0.00
Kenya	4.12	4.12	3.46	0.00
India	3.50	4.93	2.16	0.00
USSR	4.66	7.65	1.29	0.00

Note: Growth rate of K for Kenya is unknown. We assume here that it is equal to the growth rate of Y.

Growth Rates of Inputs per Capita

Economic Growth, 1950-1980

Country	Growth rate (in %) of:			
	y	k	z	A
Britain	2.05	3.07	-0.33	1.30
Germany	4.35	5.24	-0.66	3.07
USA	1.92	2.59	-1.26	1.34
Japan	6.67	6.90	-1.10	5.00
Kenya	0.66	0.66	-3.46	0.67
India	1.34	2.76	-2.16	0.76
USSR	3.37	6.36	-1.29	1.84
USSR (1976-82)	1.30	6.60	-0.90	-0.31

Note: Growth rate of A is calculated using the .25, .70 and .05 as the shares of capital, labor and resources in income respectively.

Contributions to Growth

Economic Growth, 1950-1980

Country	Share of Total Growth Explained by Factor (in %)		
	k	z	A
Britain	37.44	-0.80	63.41
Germany	30.11	-0.76	70.57
USA	33.72	-3.28	69.79
Japan	25.86	-0.82	74.96
Kenya	25.00	-26.21	101.52
India	51.49	-8.06	56.72
USSR	47.18	-1.91	54.60
USSR (1976-82)	126.92	-3.46	-23.85

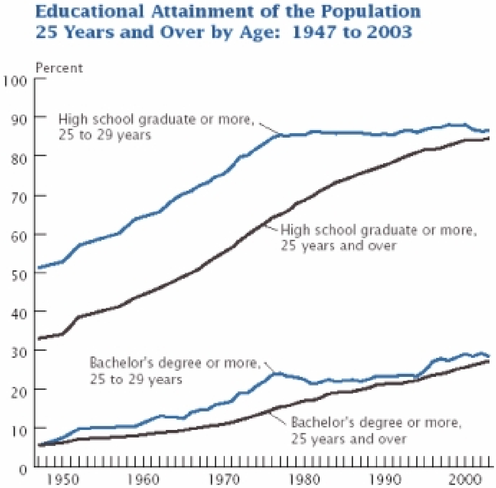
Note: Contributions are calculated using the .25, .70 and .05 as the shares of capital, labor and resources in income respectively.

Contributions to Growth

- So it seems that much of modern growth is the result of g_A
- But we need to be careful about how we interpret g_A
- We've called A technology but what exactly is it?
- Technically, its picking up everything that is not captured by K, L or Z
- What if workers are getting smarter, what if land is losing its fertility, ...? All of these things get bundled into A
- So we need to be careful, A isn't just how good our computers are or the other ways we typically think about technology

Interpreting g_A

- One big thing g_A may be picking up is increases in human capital
- This isn't really technological change, its actually an increase in an input
- It's also an input that happens to have grown a lot over the past century
- Just think about your human capital (how much money you've invested in college education)



Note: Prior to 1964, data are shown for 1947, 1950, 1952, 1957, 1959, and 1962.
Source: U.S. Census Bureau, Current Population Survey and the 1950 Census of of Population.

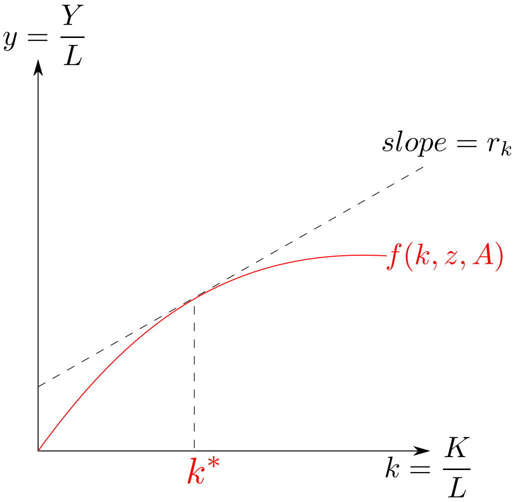
Interpreting g_A

- So if we don't adjust for the human capital of workers, we overstate the growth rate of technology
- However, we do have some ways to measure growth in the stock of human capital (how much people spend on education, how many people go to college, how much companies invest in training, etc.)
- Even if we include a term for growth in the human capital stock in our growth accounting equation, we still wind up with a pretty large g_A

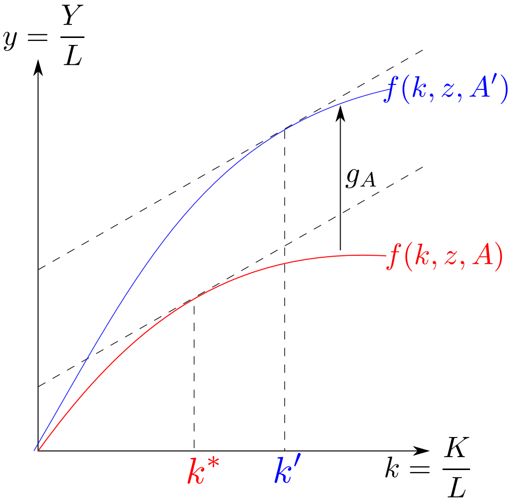
Interpreting g_A

- To make things even more complicated, some of the growth in k may actually be due to growth in A (so our method of calculating g_A would underestimate the growth in technology)
- The basic argument is the following:
  - Firms choose a level of capital at which the marginal product equals its price
  - If technology improves, the marginal product of capital increases
  - Firms will raise the level of capital per worker until they once again reach a point where the marginal product of capital equals its price
- So what we observe to be growth in capital actually might be due to growth in technology

Growth Accounting - Interpreting g_A



Growth Accounting - Interpreting g_A



Technological Change as Fundamental Source of Growth

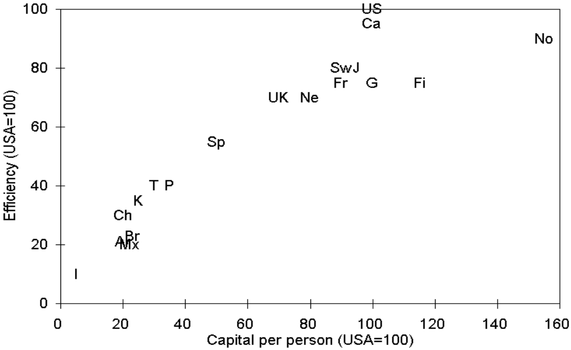


Figure: Efficiency and Capital per Person, 1989

Decomposing Growth by Industry

Total Factor Productivity Growth for the US, 1974-1999

	1974-1990	1991-1995	1996-1999
TFP growth rate	0.33	0.48	1.16
Growth in TFP by sector:			
Computer sector	11.2	11.3	16.6
Semiconductor sector	30.7	22.3	45
Other nonfarm business	0.13	0.2	0.51
Output shares:			
Computer sector	1.1	1.4	1.6
Semiconductor sector	0.3	0.5	0.9
Other nonfarm business	98.9	98.8	98.7
Contribution from each sector:			
Computer sector	0.12	0.16	0.26
Semiconductor sector	0.08	0.12	0.39
Other nonfarm business	0.13	0.2	0.5

Data are from Oliner and Sichel, 2000.

Contributions to British Growth During the Industrial Revolution

CONTRIBUTIONS TO NATIONAL PRODUCTIVITY GROWTH, 1780–1860
(percentage per annum)

Sector	McCloskey	Crafts	Harley
Cotton	0.18	0.18	0.13
Worsteds	0.06	0.06	0.05
Woolens	0.03	0.03	0.02
Iron	0.02	0.02	0.02
Canals and railroads	0.09	0.09	0.09
Shipping	0.14	0.14	0.03
Sum of modernized	0.52	0.52	0.34
Agriculture	0.12	0.12	0.19
All others	0.55	0.07	0.02
Total	1.19	0.71	0.55

Sources: McCloskey, "Industrial Revolution," p. 114; Crafts, *British Economic Growth*, p. 86; and Harley, "Reassessing the Industrial Revolution," p. 200.

One Giant Caveat

One quote from Abramovitz to keep in mind:

> *"This result is surprising in the lopsided importance which it appears to give to productivity increase, and it should be, in a sense, sobering, if not discouraging, to students of economic growth..."*

One Giant Caveat

One quote from Abramovitz to keep in mind (continued):

> *"Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the causes of economic growth..."*