Lecture notes 7: More on Technology

More on Technology

- New techniques that are just being transferred out of development and into production, great promise for higher productivity:

Optical switching, fuel-cells, and nanotechnolgy.

- Technologies that were once cutting edge are now outmoded and no longer used:
- Process of rapid TC is historically unusual.
- Dates back only 250 years in the most advanced countries.
- Prior to the current era, TC was slow and sporadic.

1. The Pace of Technological Change

We can follow a particular invention history but how do we judge the importance of one invention vs another?

Some Milestones of Technological Progress

• **Food production** (8500 BC), from hunting and gathering to planting crops and raising livestock allowed for higher population densities and the rise of complex civilizations.

• **Wheel** (3400 BC) Invented in the region of the Black Sea, it spread through Europe and Asia within a few centuries. The wheel was also invented in Mexico before the arrival of Europeans, but never found practical application.

• **Writing** Invented independently in Mesopotamia around 3000 BC and in Central America before 600 BC.

• **Padded Horse Colla**r. Invented in China around 250 BC and independently in Europe in the ninth century. By allowing a horse to pull a heavy load without choking itself, the padded collar produced a great jump in the efficiency of animal power.

• **Mechanical clock** (around 1275) Revolutionized the organization of economic activity by allowing people to coordinate their actions.

• **Moveable Type** (1453) Gutenberg's invention made practical the publication of books on a printing press. In the 50 years that followed, more books were produced in Europe than during the preceding millennium, leading to vast social as well as economic changes.

• **Steam engine** (1768) The first practical method for converting chemical energy into mechanical energy.

• **Textile manufacture** (second half of the eighteenth century) A series of inventions mechanized the spinning and weaving of cotton textiles, which were the premier industry of the Industrial Revolution. The price of cotton cloth declined by 85% between 1780 and 1850.

• **Network electricity** (last quarter of nineteenth century) This was not a single invention, but a collection including the dynamo (1870), the light bulb (1879), the transformer (1885), and the AC electric motor (1889). Together they revolutionized the transmission and use of energy.

• **Mass production of automobiles** (1908) Henry Ford did not invent that car, but by standardizing design and streamlining production, he brought automobiles within reach of the average family.

• **Transistor** (1947) This tiny electronic switch laid the basis for modern computers and telecommunications.

• **ARPANET** (1969) The predecessor to the Internet, it was created by the United States Department of Defense. The original network connected 4 host computers. A decade later, there were 188 hosts. By 2002, there were 147 million.

• **Polymerase Chain Reaction** (1985) This technique, by which a DNA fragment is rapidly reproduced, is a key tool of genetic engineering.

Technological Progress and Productivity

An alternative way of examining technological progress is to use to use data change in productivity which is associated with technological progress.

1.1 Before the Eighteenth Century

• Data are quite sparse.

• The important role that land played as in input in pre-industrial economies. Ignoring the role of land, would not be appropriate in dealing with a time period when most people worked as farmers and when most wealth was held in the form of land.

• Therefore we consider a production function in which the only factors of production are labor (L) and land (X):

(1) $$Gy = AX^{\beta}L^{1-\beta}$$

(2) $$Gy = A\left(\frac{X}{L}\right)^{\beta}$$

(3) $$G\hat{y} = \hat{A} + \beta\hat{X} - \beta\hat{L}$$

(4) $$\hat{A} = \hat{y} + \beta\hat{L}$$

Table 1: Growth Accounting for Europe, 500-1700 AD (annual %)

Period	Growth Rate Income pc	Growth Rate of Population	Growth Rate of Productivity
500-1500	0.0%	0.1%	0.033%
1500-1700	0.1%	0.2%	0.166%

1.2 The Industrial Revolution

• The most significant turning point in the history of technological progress was the **Industrial Revolution**, which is generally dated as having taken place between 1760-1830 in Britain, spreading somewhat later to Continental Europe and North America.

• A period of rapid technological innovation in a number of industries. Most significantly, beginnings of mechanization of production that would allow tasks that had been performed by skilled artisans to be transferred to machines that could work faster and tirelessly.

• Three of the most important areas of change were:

1) ***Textiles***: the centerpiece of the industrial revolution. A wave of new inventions revolutionized the process of spinning, weaving, and printing fabric. E.X., the amount of time required for a worker to spin one pound of cotton into thread fell from 500 hours to only three. British production of cotton textiles rose by a factor of 125 between 1770 and 1841, and prices plummeted.

2) ***Energy***. Wind, water, animals, and human muscle had been the only sources of mechanical energy for millennia. Thus the steam engine, in which burning fuel produced steam to drive a piston, represented a revolutionary break with the past. The development of the steam engine allowed the vast chemical energy contained coal deposits to be tapped as a source of mechanical energy. Between 1750-1850, British production of coal rose ten-fold. Steam engines also revolutionized transportation, beginning with Robert Fulton’s steamboat in 1807 and spreading later to railroads (the first steam railway opened in 1825).

3) ***Metallurg*y**. The widespread adoption of coal as a replacement for wood as a source of fuel in iron smelting, as well as several important technical innovations lead to a dramatic decline in the cost of iron production. Figure 1: the resulting increase in output.

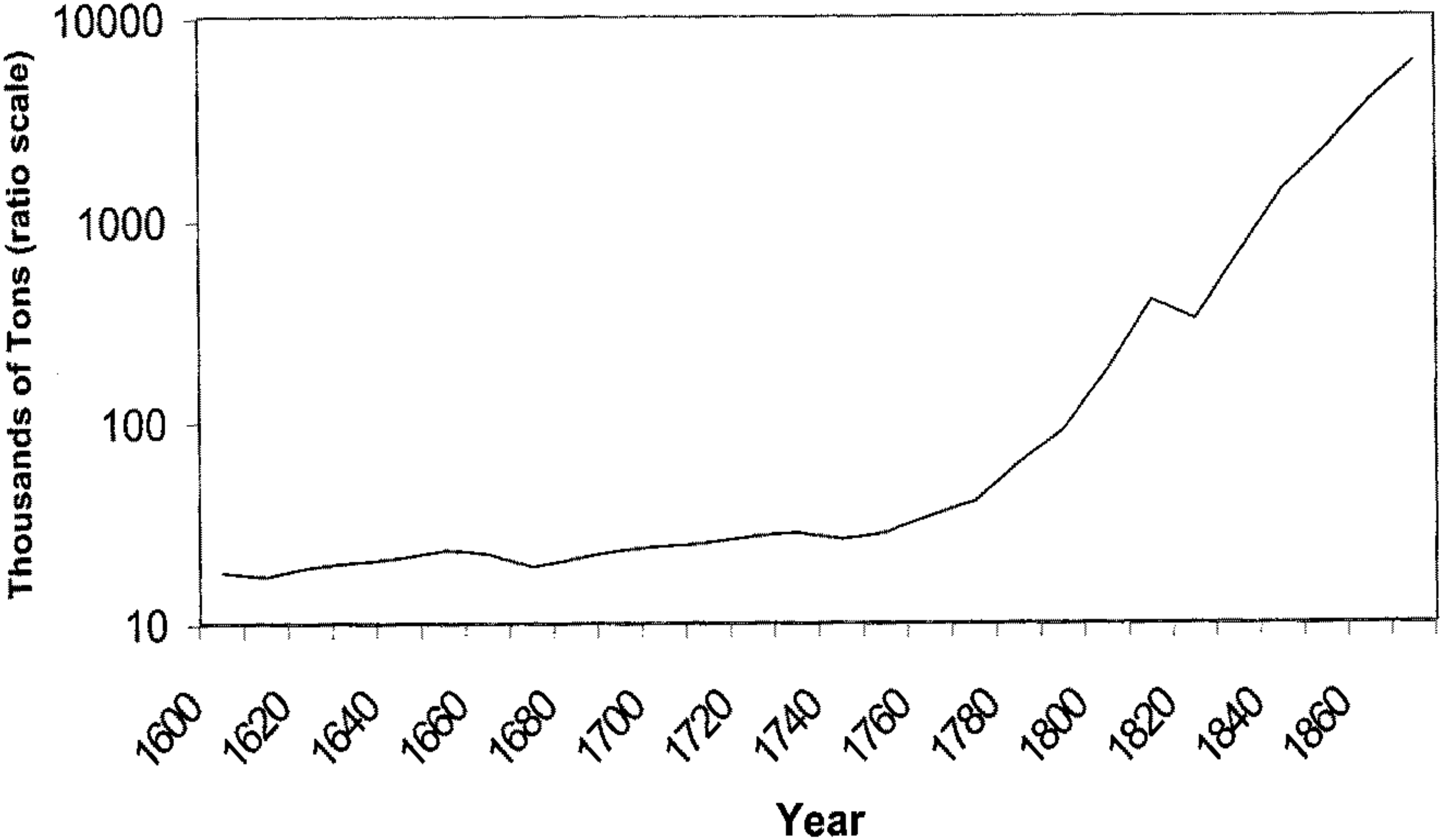
Along with these changes in production technology, there were shifts in the overall structure of the economy:

• Between 1760-1831, fraction British labor force employed in agriculture, forestry and fishing fell by half, from 48% to 25%, while the fraction employed in industry and mining rose from 22% to 41%. • Fraction British population living in cities rose from one sixth to one half over the period 1700-1850.
• 2,400 miles of canals were constructed between 1760 and 1835.

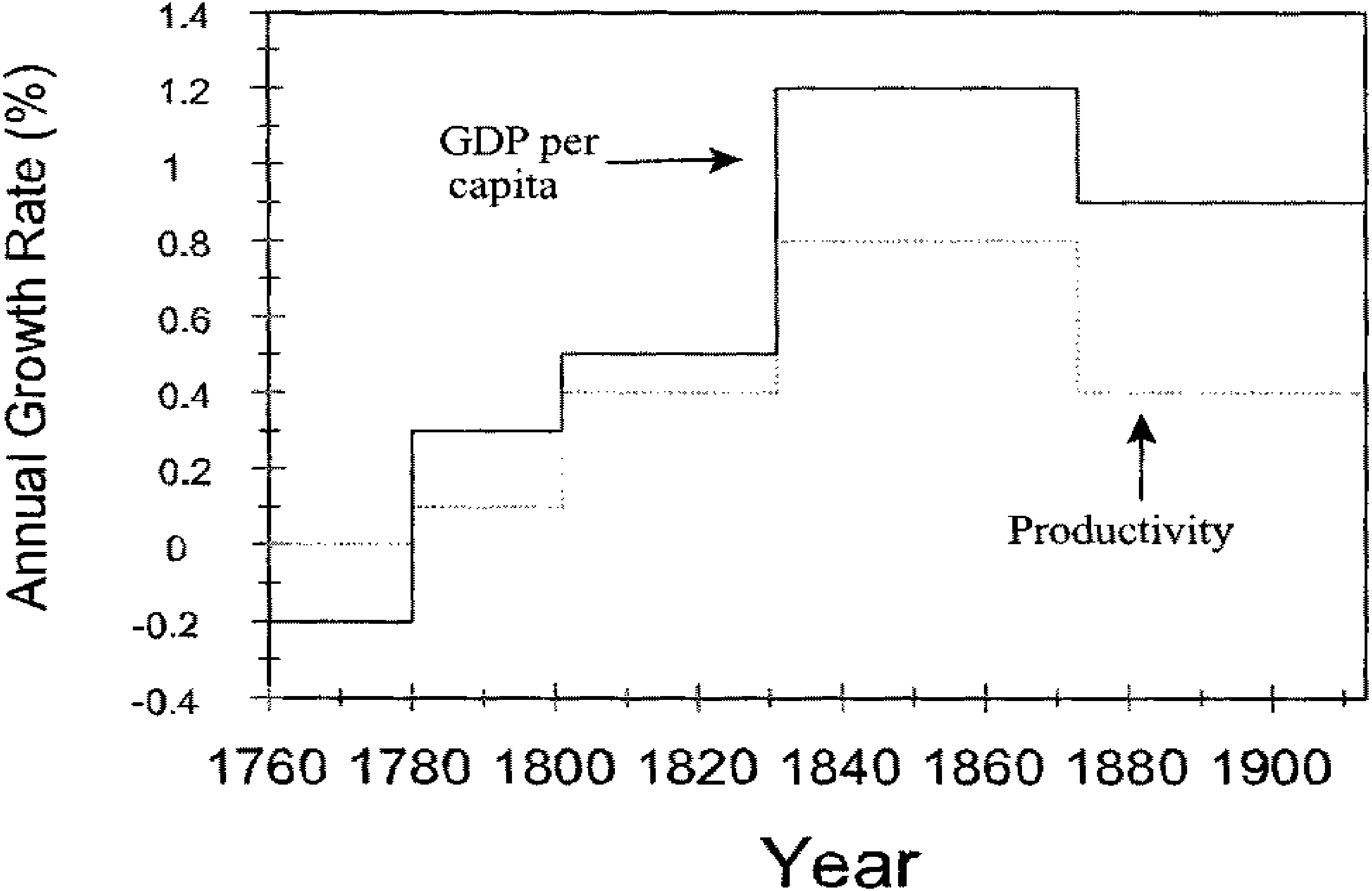
Figure 2 shows data on the growth rate of GDP per capita and productivity in Britain over the period 1760-1913.

Figure 9.1

British Iron Production 1600-1870



British Output and Productivity Growth: 1760-1913



1. The technologies introduced during the IR were revolutionary, but their immediate impact on economic growth was small because they were initially confined to few industries.

2. More significantly, the Industrial Revolution was a *beginning.* Rapid technological change, the replacement of old production processes with new ones, the continuous introduction of new goods – all of these things that we take for granted today got their start during the Industrial Revolution.

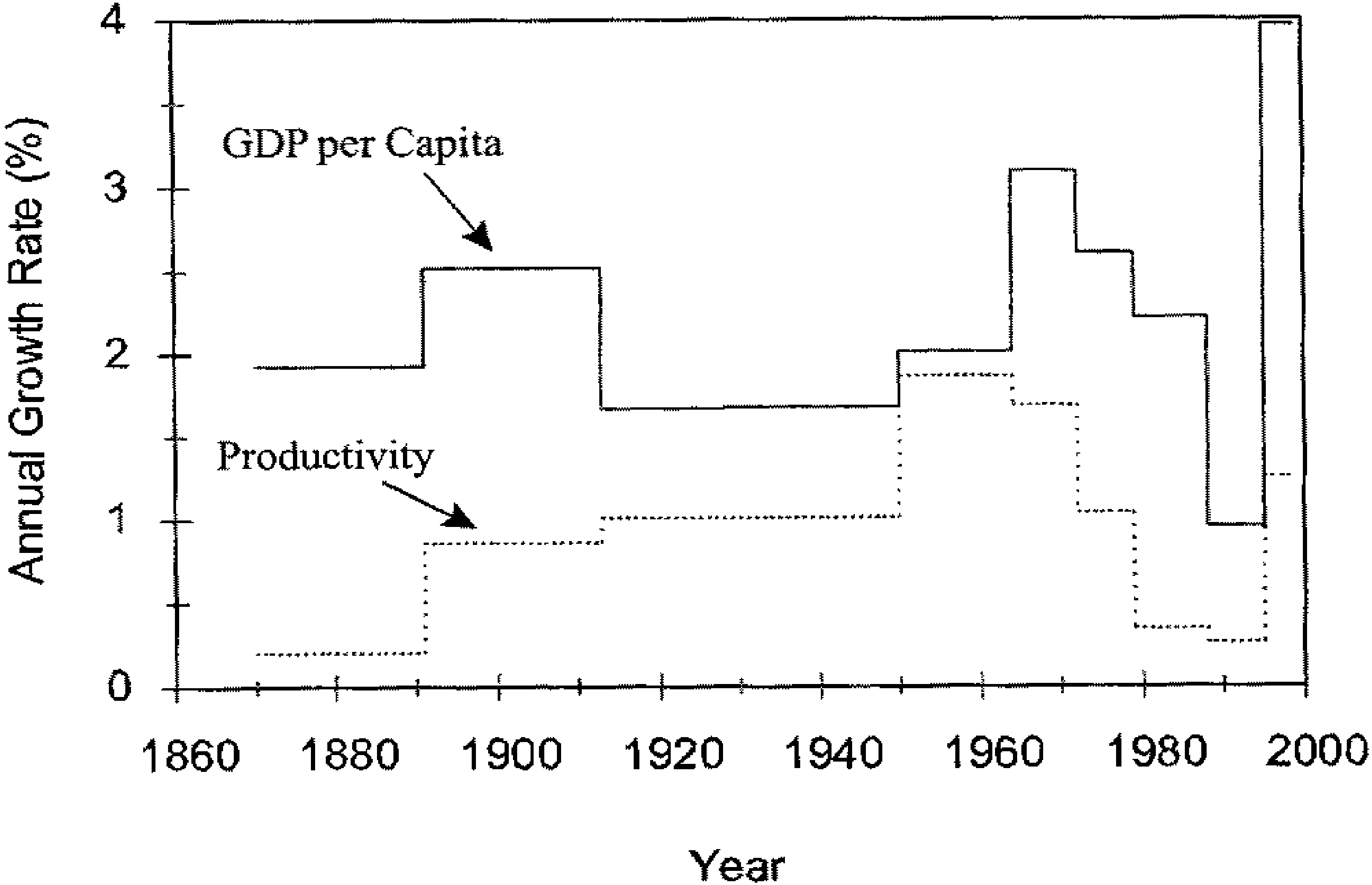
3. While the actual growth rates achieved during this period do not look revolutionary in retrospect, the process of continual growth that
began then was indeed revolutionary in comparison to what had come before.

1.3 The Pace of Technological Progress Since the Industrial Revolution

Figure 3: from 1890 to 1972 daily life in the most DC was transformed more dramatically than ever before in history.

1. Among the most important changes were electric light, refrigeration, air conditioning, the telephone, the automobile, air travel, radio, television, and indoor plumbing. Many were invented earlier in the 19'th century, but took several decades before they spread to the economy as a whole – a process that is known as **diffusion**.
2. E.X., the electric lightbulb was invented in 1879, but by 1899, only 3% of households in the US had electric light. It took another three decades, until 1929, before 70% of households were using this technology.
3. A second point that emerges from Figure 3 is that there was a dramatic reduction in the growth of productivity starting in the early 1970s. Having averaged 1.2% per year over the period 1890-1971, productivity growth fell to an annual rate of 0.55% between 1972 and 1995.
4. This **productivity slowdow**n, which took place not only in the US but throughout the developing world, was one of the most puzzling phenomena of the post-World War II era. Many observers feared that the period of rapid technological progress that had done so much to change LS had abruptly come to an end.

US Output and Productivity Growth: 1870-2000



What caused the productivity slowdown?

- Productivity is not the same as technology. Although in the long run productivity growth mostly comes from improvements in technology, in any given time period there can be changes in productivity that have more to do with the organization of the economy than with changes in technology – called efficiency.
- Thus the fact that productivity growth slowed down in the 1970's and 80's does not necessarily mean that the growth rate of *technology* had fallen. Indeed, there is good reason to think that the period of time of the productivity slowdown is one in which the *efficiency* of the US economy fell (oil prices increased from 1973 to 1979, massive recessions in 1974 and then in 1981.
- A final striking aspect of Figure 3: starting in the mid-1990s, there was another dramatic change in the trend, with productivity growth rising above its pre-slowdown levels. Some economists see in this data the beginning of a “third industrial revolution,” centered around information technologies.

General Purpose Technologies

How does technological progress proceed? In an even flow or in dramatic waves?

- In recent years a focus on the latter view: that there are certain drastic technological innovations which change the entire nature of the economy.
- These **general purpose technologies**, such as the steam engine, network electricity, and railroads, have two important characteristics:
  - They change the mode of production in many different sectors of the economy;
  - They trigger a chain reaction of complimentary inventions that take advantage of the new technological paradigm.
- Because of the trail of complementary inventions that follow in its wake, the period of growth resulting from a single general purpose technology can go on for several decades, E.X., the electric motor.

- Although electric motors were first used in manufacturing in 1883, their diffusion was initially very slow:
  - At the beginning of the 20'th century, steam engines provided 80% of the mechanical drive used in US factories, with most of the remainder being supplied by water wheels and turbines.
  - By 1929, however, 79% of mechanical drive was being supplied by electric motors. The first effect of electric power was a gain in energy efficiency, but this turned out to be only the beginning.
  - The more important change from electricity would be in the production process itself. In factories powered by steam, a large steam engine would turn a shaft, which ran the length of the factory; individual machines would then be powered by belts which brought power from the central shaft.

Another example of general purpose technology: The semiconductor:

Transistors and integrated circuits - Basis for modern computers.

- Initial diffusion was slow (the first industry to adopt transistors, in the early 1950s, was hearing aids).
- Over time, however, semiconductor-based computers have penetrated to almost every sector of the economy.
- But as computers spread through the economy in the 1980s, the growth rate of productivity remained dismally low.
- Then in the second half of the 1990s, the productivity growth sped up.
- In the view of many economists this productivity speedup was due to the computer finally coming into its own as a productive instrument Just as it had taken businesses decades to learn how to take advantage of electric motors to redesign their production processes, it had taken them decades to learn how to exploit the capabilities of semiconductors.

2. The Technology Production Function

Figure 4 shows a measure of input into technology production: the number of scientists engaged in research and development in the G-5 countries (US, UK, France, Germany, and Japan) over the period 1950-93.

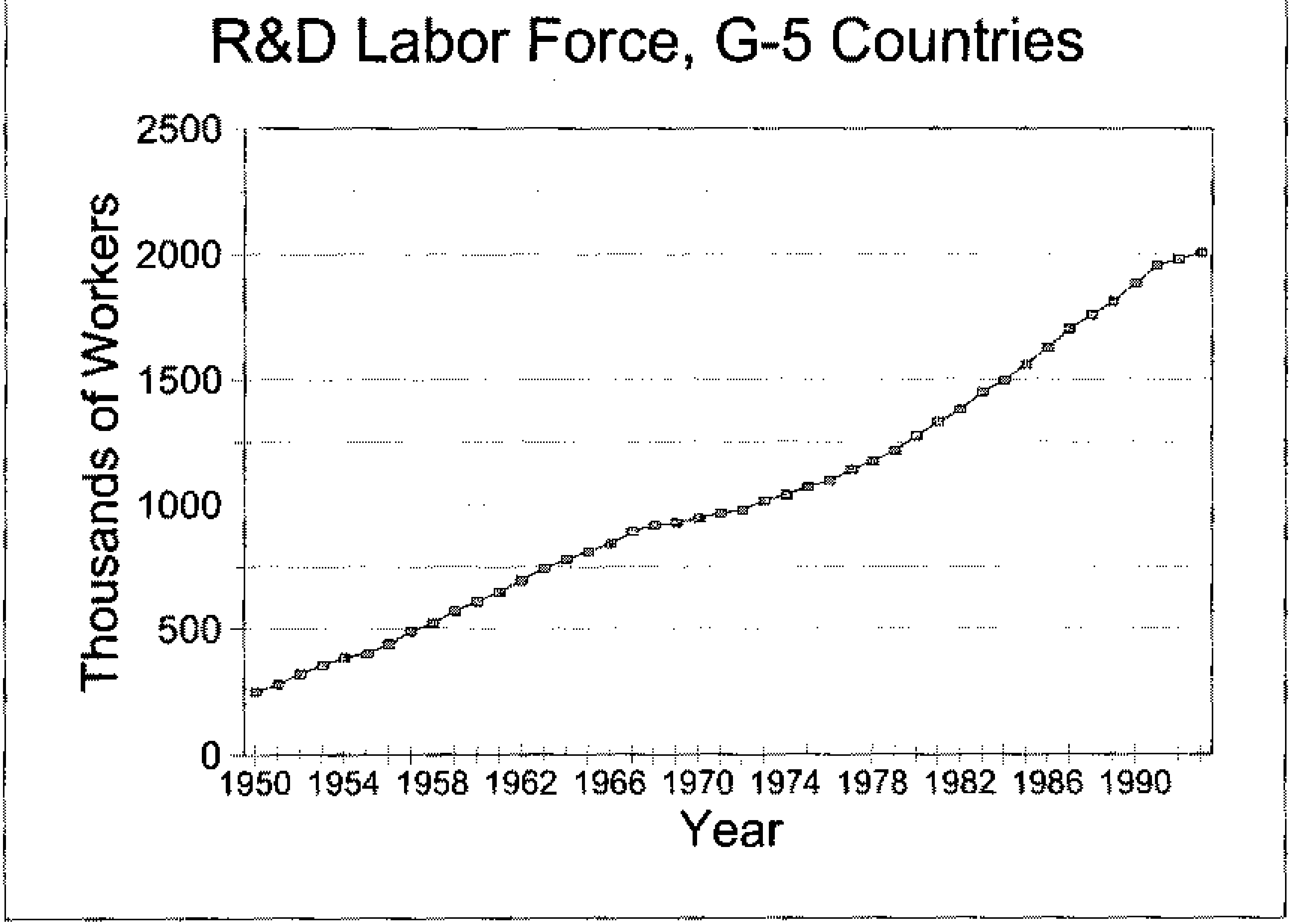
*The input to technological progress has grown substantially over time, while the growth rate of technology has no*t.

$$\hat{A} = \frac{L_A}{\mu} \quad (1)$$

• Because the easiest discoveries have already been made. This is called the **fishing out effect.** Further, because more is known today than in the past, it takes more effort for a researcher to learn everything required to work at the cutting edge.

• Equation (1) makes a subtle assumption about this issue that turns out to be very important. Specifically, it assumes that the growth rate of technology depends *only* on the amount of resources devoted to R&D, and not on the level of technology itself. In other words, the benefits of having better tools to work with exactly cancels out the negative effects of having already made the easier discoveries.

Figure 9.4


R&D Labor Force, G-5 Countries
2500
2000
1500
1000
500
0
Thousands of Workers
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
Year

Science and Technology

- Science represents our understanding about how the world works, that is, about physical and biological processes.
- Technology, by contrast, represents the knowledge of techniques of production.

What is the relationship between the two?

- For most of human history, technological advance was largely unrelated to any scientific understanding of the rules by which the universe operated. Technologies that were productive were discovered by trial and error, rather than through any understanding of why a certain procedure led to a given outcome. Indeed, if there was any connection between science and technology, it was that technological advance opened the way for greater scientific understanding.

• There are at least two important ways in which advances in science have been the result of technological improvements:

1. technology posed many puzzles which scientists then strove to solve. In one of the most famous cases of this phenomenon, the French scientist Sadi Carnot worked out the laws of thermodynamics in 1824 by trying to figure out why a high-pressure steam engine was more efficient than a low-pressure engine. Similarly, the mystery of why canned foods did not spoil was one of the puzzles which led Louis Pasteur into his studies of microbiology.

2. A second way in which technological improvements can led to scientific advance was by providing scientists with the tools to conduct better experiments and observations. Tools such as the microscope (invented in 1590) and telescope (invented around 1600) literally opened up new worlds for scientific investigation. In a recent example of this phenomenon, the decoding of the human genome was vastly speeded up by the use of high-speed DNA sequencing machines.

• It was during the first half of the 19’th century that scientists began to repay their debt to technology. The technologies of the first IR (1760-1830), including advances in cotton spinning and steam power, were not dependent on scientific advances. The technologies of the second IR (1860-1900), including steel, chemicals, and electricity, could not have been developed in the absence of new scientific understandings.

• In the 20’th century, this shift toward science-driven technological advance has continued. Technological breakthroughs like the semiconductor, laser, and nuclear power, for example, rested solidly on new scientific understandings of how the universe functioned. Advances in physics depend crucially on new pieces of technology such as better particle accelerators. And there remain many examples of technological advance that takes place without the benefit of scientific understanding.

Modeling the fishing out effect, namely allow the level of technology to the affect the rate of technology as follows:

Including in equation 1

$$\hat{A} = \frac{L_A}{\mu} \quad (1)$$

A itslef to the power of - Φ as follows:

$$\hat{A} = \frac{L_A}{\mu} A[power(-)\phi] \quad (2)$$

Where 0 <Φ <1

For a given labor force in A and μ, TC will be slower, the higher is the current level of technology. The value of Φ determine the strength of this effect.

If **Φ=1/2, quadrupling A will reduce by half the rate of growth of technology for a given labor input into R&D**

Decreasing Returns to Scale in R&D.

- Obviously, if we doubled the number of researchers without changing the quantity of capital used in R&D – we would not expect this to lead to a doubling of the speed of technological progress.
- Rather we are asking the question: what if we doubled the quantities of *all* resources devoted to R&D.

- In equation 1, the growth rate of technology is simply proportional to the number of people engaged in R&D. Is this a reasonable assumption?
- For the technology PF, CRS is not appropriate. Instead, this function is characterized by DRS which arise from the qualities of knowledge itself. Once a piece of knowledge has been created, it can be costlessly shared among any number of people – “non-rivalry”.
- This means that if several people are all trying to create the same piece of knowledge, the efforts of most of them will end up being wasted – only one will be the first.
- E.X., Alfred Wallace worked years on a theory of natural selection, only to be scooped by Charles Darwin.

Implications for the Future of Technological Progress

The two modifications listed above can be summarized as follows:

- First, as the level of technology rises, finding new discoveries becomes ever harder;
- Second, as the effort devoted to R&D increases, the effectiveness of each new researcher falls.

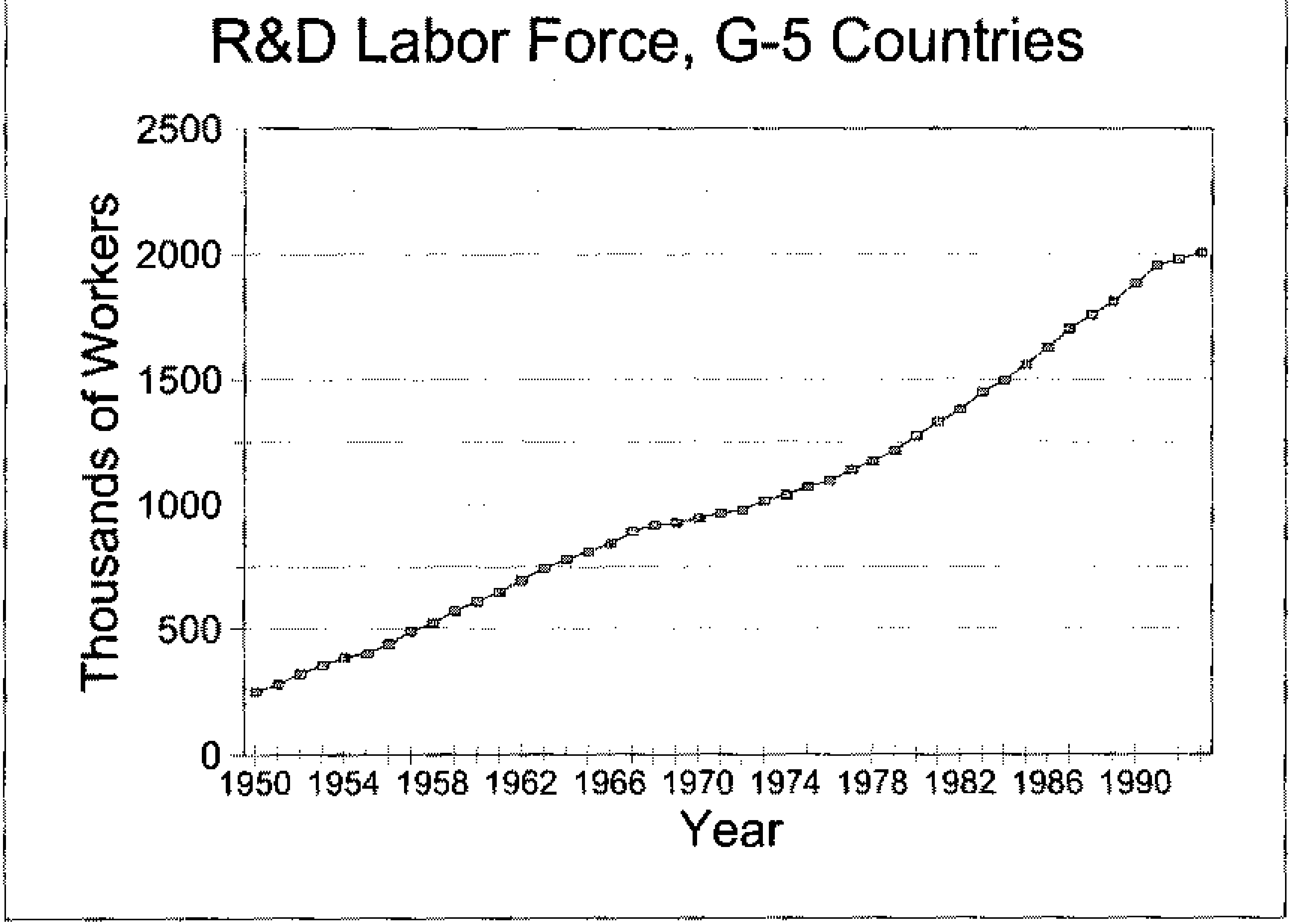
Both of these modifications imply that ever increasing input into R&D will be required to maintain the current speed of technological progress.

- Figure 4 shows that over the period 1950 to 1993, the number of researchers in the G-5 countries grew from 251,000 to just over two million – a factor or eight in a period of 43 years.

- If this same ratio applies in the future, then to maintain the same rate of technological progress over the subsequent 43 years, will require a similar 8-fold increase in the number of researchers, from 2 million in 1993 to 16 million in 2036.

- And, extending the analysis further, to 128 million in the year 2079!
- Is such an increase possible? Or will technological progress inevitably slow down?

Figure 9.4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To answer this question requires looking at **three** possible sources of growth in the amount of labor devoted to R&D.

1) *Growth in the labor force overal*l.

• One of the factors that allowed growth in the # of researchers over the last half century has been the growth of the labor force, due both to growth in the population and to the increase in the labor force participation rate of women.

• Most of DC, are not expected to experience significant growth in population and labor force participation over the next several decades.

2) *Growth in the fraction of the labor force that is engaged in research* In the US, the fraction of the labor force that is engaged in R&D rose from roughly 0.25% in 1950 to 0.75% in 1995, and similar increases were seen in other DC. It was this increase that was responsible for the large rise in the number of researchers.

• Will this expansion in the fraction of the labor force doing R&D continue into the future?

In the very long run, the answer obviously has to be "no", but probably "yes" in the short run.

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Where is the cutting edge of technology?

- Patents are an imperfect measure of technological activity. In some industries, inventions tend not to be patented because it is more useful to keep them secret.
- Countries which specialize in these industries may have a low rate of patenting even though they are technologically advanced.
- Similarly, there are many localities that are certainly part of the technological cutting edge even if the countries where they are located are not.
- The best example is the city of Bangalore, in India, which is home to a huge software industry. Indeed, one effect of globalization is that it is increasingly difficult to pinpoint a geographic area that corresponds to the cutting edge of technology.

Table 2: US Patents per Million Residents, 1997

Japan	192.8
Switzerland	165.9
Taiwan	114.9
Sweden	112.5
Israel	98.2
Finland	93.8
Canada	92.5
Germany	87.5
Denmark	68.5
Luxembourg	66.4
Netherlands	56.3
Belgium	54.9
France	53.3
Austria	48.4
UK	47.2
South Korea	39.7
Hong Kong	39.2
Singapore	35.8
Norway	35.4
Australia	31.9
New Zealand	25.3
Italy	24.7
Ireland	21.0
Iceland	14.7

3) *The inclusion of new members in the set of countries which are doing cutting-edge research*.

- Looking at the list of countries at the cutting edge of research, it is clear that many of them are newcomers. Japan, Taiwan, Israel, South Korea, and Singapore were certainly not at the cutting edge of technology in the middle of the 20 th century. And even fewer of the countries listed in Table 2 would have been at the cutting edge of technology in 1900 or 1850.
- The addition of new members to the group of cutting edge countries has expanded the labor pool from which researchers can be drawn. Even today, however, the countries at the cutting edge of technology account for only 15% of world population, and so there good reason to expect that this expansion of countries at the cutting edge of technology will continue.
- In the very long run, however, the prospects are less optimistic. Assuming that the population of the world eventually stabilizes, there will have to come a time when the amount of labor devoted to R&D will stop rising. At that point, growth rate of technology might slow down.

Allowing for decreasing return to scale:

We raise the labor input into R&D to some power less than one:

$$(2) \quad \hat{A} = \frac{L_A[power\lambda]}{\mu}$$

$0 < \lambda < 1$

If labor in R&D is constant, then the growth rate of technology should also be constant. I the R&D effort rises, then growth rate of technology should also rise. But, because of the decreasing return to scale, the response will be less than proportional. If, for example, $\lambda=1/2$ then raising labor input in R&D by four times will only double the rate of growth of technology.

Combining the level effect of A and decreasing return to scale:

$$\hat{A} = \frac{1}{\mu} L_A^{\lambda} A^{-\phi}$$

We can calculate the relationship between growth rates of R&D input and technology. If $\hat{A}$

Is constant, then it must be the case that the product $L_A^{\lambda} A^{-\phi}$

Is also constant. Then

$$x = L_A^{\lambda} A^{-\phi}$$

Where x is a constant. Taking log of both sides and differentiating with respect to time, we get

$$0 = \lambda \hat{L}_A - \phi \hat{A}$$

After rearranging terms we get:

$$\hat{A} = (\lambda / \phi)\,\hat{L}_A.$$

Given the parameters of the above equation we can solve what rate of technological progress is consistent with a given growth rate of R&D labor.

Or if we know the growth rate of technical change and of R&D labor we can solve for the following ratio: (λ / ϕ)