2 Economic Growth
In this chapter you will learn:
- Facts about the growth rate in the US
- Different explanations of the facts
- Production functions
- Diminishing marginal product (returns)
- The Leontief production function
- The classic Solow growth model
- New growth theories: human capital, knowledge, infrastructure.
- The capital – skilled labor hypothesis and the income distribution.

2.1 Introduction
We turn our attention now to economic growth and how growth can alleviate scarcity. The models we will use are examples of general equilibrium, or equilibrium for the entire economy rather than just one market. This is "big picture" thinking. However, economic growth is generated at the individual level through the decisions of individual producers, innovators, savers, and people investing in education. We will introduce the production function to capture the technology and describe one of the most important concepts in economics, diminishing marginal returns. We will also see how diminishing marginal returns can reduce growth, and how technological innovation and human capital can overcome diminishing marginal returns.

Economic growth is typically measured by changes in Gross Domestic Product. We can depict economic growth geometrically by having the production possibility frontier shift out over time, as mentioned in the last chapter. The greater the growth rate of the economy, the more it shifts out. If growth is negative, GDP is falling and the PPF shifts back instead.

Most of the world's economic growth has occurred since the industrial and scientific revolution began in the late 18th century. Prior to that most economies were relatively stable in the sense that economic events followed a fixed pattern with little variation and the pattern followed the cycle of agriculture; planting in the spring, harvesting in the fall, storing for the winter, and so on. Occasionally, there would be a deviation from the pattern due to drought, an especially hard winter, or war. After the interruption was over, however, life typically returned to the old pattern.

This pattern was broken by the scientific revolution. After 1800, people began inventing labor saving devices that started the process of substituting capital for labor. For example, more efficient plows were developed which reduced the amount of time it took to plow a field and this in turn freed up labor for other uses. Waterwheels were made more efficient and it became easier to mill grain. The steam engine and ships powered by a steam engine were far superior to ships powered by the wind. Railroads were far more efficient than horse drawn carriages for transporting goods over land. This is important because it reduced transportation costs. A manufacturer could ship his goods to markets farther away broadening markets.

A comparison for the US: The twentieth century

<table>
<thead>
<tr>
<th></th>
<th>life expectancy</th>
<th>workweek</th>
<th>school enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>47.6 years</td>
<td>59.1 hours</td>
<td>50.5%</td>
</tr>
<tr>
<td>1999</td>
<td>77 years</td>
<td>34.5 hours</td>
<td>92%</td>
</tr>
</tbody>
</table>

(Sources: Bureau of Labor Statistics, Census Bureau, Statistical Abstract)

As an economy develops, machines do many of the tasks that labor used to do, the efficiency of the economy improves as a result, and life gets a bit easier. Consider the data from the last
century for the US. Notice that the average workweek has fallen dramatically during the 20th century as real GDP increased. So we are able to produce more even though the average person is working less. This is because we are producing more efficiently. In addition to this, the quality of life has improved dramatically as health and longevity increased.

We should note that not all economies grow and expand. Some decay and get smaller. Examples include North Korea since the early 1950's, Uganda in the 1970's, Haiti in the 1980's, 1990's and 2000’s, Somalia, Rwanda, Burundi, and Bosnia in the 1990’s, Iraq in the 2000s, and Syria in the 2010’s. Even the U.S. contracted in 1930-33 during the Great Depression.¹

As it turns out, small differences in the growth rate can lead to large differences in the size of an economy over time. It is useful to think of economic growth as you would compound interest. Suppose you invest $1 at x%, where x is the interest rate. The $1 will grow over time and the larger x is, the faster it will grow. The same is true of economic growth. Imagine GDP per capita is $1 and is growing at x% each year. It will grow in exactly the same way as $1 invested at x%.

It is instructive to compare two economies that are alike in every respect except that one is 3% per year while the other is growing at 1%, and suppose both economies start off with a GDP equal to $1. After 75 years they will differ dramatically as growth "compounds," as depicted in the diagram. After 75 years the economy growing at 1% will barely double in size to $2, while the economy growing at 3% will increase almost 9 and a half times. Which economy would you rather live in?

Why is this so important? Remember how your parents would claim how hard they had it when they were your age? In a sense this is true. Why? Economic growth. Growth brings innovations and new products that make life easier. It also increases income and raises the standard of living. And people do tend to forget what the last generation had to endure. Keep in mind that as late as 1930, most of our country did not have electricity or indoor plumbing. Indeed, most of the gadgets that you now use every day and take for granted are relatively new, having come into widespread use in only the last twenty or thirty years like laptops, smart phones, the Internet, streaming video, LCD tv’s, interactive online games, even microwave ovens, air bags, and anti-lock braking mechanisms. There have also been tremendous innovations in a number of areas that one is not normally aware of like high speed digital

¹ On growth in the Great Depression, see http://research.stlouisfed.org/fred2
computing, robotic surgery, high tech pharmaceutical drug therapies, the avionics that guide jet aircraft, automobile design, and space exploration on Mars. Finally, if you are running a company it is much easier to increase your sales in an economy where the standard of living is growing than one where it is not.

2.2 Recent Evidence
Recall the numerical definition of economic growth from the last chapter. The growth rate of a variable \( X \) is defined as

\[
\text{growth rate} = \frac{X_t - X_{t-1}}{X_{t-1}}.
\]

where \( X_t \) is the value of \( X \) at time \( t \). To put it in percentage terms multiply by 100\%. When studying economic growth, we usually take \( X \) to be a measure of the economy's performance like GDP or personal income. For an individual firm it would be something like retail sales or accounting profit.\(^2\)

In the chart we present data on the growth rate in real GDP for each decade since 1950 for the US. The growth rate was highest in the 1960s at just under 5\%, second highest in the 1990s, and was lowest in the first decade of the 2000s, below 2\%. The US was fighting the war in Vietnam and engaged in the space race to put a man on the moon in the 1960s. In the 1990s companies finally figured out how to fully employ computer technology in their businesses.

![Growth in RGDP](image)

(Source: FRED, real GDP series annual data, US, 1929 – 2014)

In the following chart we present the growth rate in real GDP organized by President. One should interpret this data very cautiously. Obviously, the President doesn’t get to choose the growth rate by himself. Policies pursued by the President when passed by Congress may have an appreciable impact on the growth rate. Sometimes Congress works well with the President and sometimes not. Occasionally, there are fortuitous innovations that occur that increase the growth rate but have nothing to do with government policy. And sometimes a policy can have unintended consequences for the growth rate that no one thought of when the policy was introduced. For example, the space race of the 1960s created jobs and improved our technology.

---

\(^2\) Imagine a column of numbers in a spreadsheet. Call the numbers \( X \) so \( X_1 \) is the first number in the column, \( X_2 \) is the second number, \( X_t \) is the \( t \)-th number, and so on. We can use the formula to calculate the growth rate from time 1 to time 2, \( (X_2 - X_1)/X_1 \), and so on for any two values of \( X \).
and may have contributed to the increase in the growth rate in the 1960s. However, this was completely unintended; it was a beneficial side effect.

Notice from the chart that there is greater variability of the growth rate when we look at shorter periods of time. The three fastest periods of growth since WWII are in the early 1960s, the late 1960s, and the late 1990s, while the slowest periods were the early 2000s, the early 1970s, and the early 1990s.

Another crucial aspect of growth is whether or not the economy is creating new jobs. The following two charts depict the experience of employment in the US. More jobs were created in the 1970s than any other decade. This is when the large baby boomer generation entered the job market. Job growth was strongest in the 1970s and the 1960s but has tapered off since then. Hardly any jobs were created in the 2000s because of the slow growth of the early 2000s and the Great Recession of 2008-09.
Application: The steel industry provides a good case study. In 1970, about 550,000 people were employed in the steel industry in the United States. The industry was very hard hit during the 1970’s, mostly by foreign competition from Japan and South Korea. Ironically, even US auto companies, the largest buyer of steel in the world, reduced their demand for US made steel because they were trying to make their cars lighter to be more fuel efficient and Japanese steel was high quality and inexpensive. However, US steel companies made a dramatic comeback during the ‘90s with the introduction of new technology and now are the world leaders in specialty steel products and high quality grades of steel. By 1995 the US was producing about the same amount of tonnage in steel as in 1970. Indeed, we now export more high quality steel to Japan than we import. However, there were only about 330,000 workers in the US steel industry in 1995. New high speed, computer controlled robotics were introduced thus eliminating over 200,000 jobs. This lowered cost enough so US steel companies could compete worldwide.

The long run growth rate of real GDP from 1947 – 1975 was about 3.7%. Unfortunately, it fell to 2.8% from 1975 – 2014. The latter period saw several changes that were significant, the entry of women into the full time work force, baby boomers entering their most productive work years, and the widespread use of computers. Since these forces have already played out, it is possible the growth rate in the future will be lower than 2.8%, perhaps less than 2%, which is cause for concern. Why does the growth rate tend to fall over time? Is there a way to reverse it?

2.3 Explaining Economic Growth: An Application of Diminishing Returns

The amount of output a worker can produce depends on how much capital and other inputs the worker has to work with. A worker who uses more capital, for example, will produce more output. A farmer can plow a field more efficiently with a tractor than with oxen. A mechanic can diagnose the problem your car is having if he has diagnostic equipment. A dentist has a better chance of saving your tooth if she has more than a pair of pliers to work with.

This is a general proposition; worker productivity depends on how much capital the firm has available. To fix ideas, let $y = \text{output per worker}$, $k = \text{capital per worker}$, $\Delta y = \text{the change in output per worker}$, and $\Delta k = \text{the change in capital per worker}$. If capital increases, then $\Delta k > 0$, and since the extra capital produces more output, $\Delta y > 0$ as well. The ratio $\Delta y/\Delta k$ is the key. This is the extra output per worker the firm can produce when capital per worker increases.

We can represent the relationship between capital per worker and output per worker as a function, $y = f(k)$, which says output per worker depends on capital per worker. The graph of this function is depicted below where $k$ is on the X-axis and $y$ is on the Y-axis. If the firm doesn't
have any capital, it cannot produce so \((0, 0)\) is on the production curve. As \(k\) increases, so does \(y\) so the curve has positive slope, \(\Delta y/\Delta k > 0\), which is the rise over the run. Notice that the curve gets flatter as \(k\) increases so the slope decreases as \(k\) increases; \(\Delta y/\Delta k\) gets smaller as \(k\) increases.

For example, suppose that initially when the firm adds one unit of capital per worker (\(\Delta k = 1\)) it can increase output by 7 units each shift. In that case, \(\Delta y = 7\) and \(\Delta y/\Delta k = 7/1 = 7\). However, if output only increases by 2 units each shift with the same increase in capital per worker, then \(\Delta y/\Delta k = 2\), and it will be much harder for the firm to expand its operations. It will have to invest in more capital in order to get more output to sell.

Now imagine that when the firm initially begins production and adds one unit of capital per worker (\(\Delta k = 1\)) it gets an extra 7 units of output (\(\Delta y = 7\)). Suppose it adds another unit of capital (\(\Delta k = 1\)) but only gets 5 extra units of output (\(\Delta y = 5\)). Finally, suppose that if it adds yet another unit of capital (\(\Delta k = 1\)) it only gets 2 extra units of output (\(\Delta y = 2\)). Each time it adds more capital it gets more output, 7, 5, and 2 are all positive, but the extra output it gets diminishes. This is an example of diminishing marginal returns and is depicted in the diagram above. The firm starts at point A, adds one unit of capital per worker, and output increases by 7 units as the firm moves from point A to B. It adds one more unit of capital and increases output by 5 units in moving from B to C, and so on. If the marginal returns are diminishing, the production curve between output and capital per worker is concave from below, as depicted above. If marginal returns are increasing instead, the curve is concave from above.

In general, **diminishing marginal returns, or diminishing marginal product**, states simply that **as more of a single input is used, less additional output is produced, holding everything else (technology, other inputs, government regulations) constant**. Typically, when individual industries are studied, it is discovered that diminishing marginal returns do actually occur. In fact, this concept is more universal than you might think. Have you seen the movie *Raiders of the Lost Ark* starring Harrison Ford? Remember the first ten minutes? That segment is probably the best action sequence I have ever seen. How did you feel the second time you saw it? Was it as thrilling as the first time? Probably not. Why? Diminishing marginal returns.
Some production may be characterized by first increasing marginal returns eventually followed by diminishing or decreasing marginal returns. This is depicted in the figure.

2.4 History of growth theory
It is useful to review a little history because some of the points made by earlier writers remain true today. In particular, Thomas Malthus's ideas about growth and development two hundred years ago are directly pertinent to discussions of growth and development today.

2.4.1 Thomas Malthus
Malthus was a keen observer of British society circa 1800, just at the start of the Industrial Revolution. He noticed that most people in England lived in dreadful poverty. They were malnourished, suffered from a broad range of illnesses, few of which could be treated, and died young. Most lived in cramped, crowded conditions, and they did not expect their prospects to improve much as they got older. In addition, most production was labor intensive and there was a fixed amount of land and natural resources available for production, and the technology was relatively fixed.

Malthus based his theory of growth on these empirical facts. He argued that if there was an increase in prosperity for some reason, e.g., a bountiful harvest, or a war ending in victory, then producers would increase production, jobs would be created, more goods would be produced, and workers would experience a higher wage. However, this improvement in the standard of living would only be temporary. A higher standard of living would lead to people having more children and eventually the new children would hit the labor market, compete for jobs and lower wages once more. Growth would eventually stop thus ending the prosperity. Indeed, in England at the time, the new children would hit the labor market at the ripe old age of six or seven, and compete with adults for wages. Eventually, most of society would be living at a subsistence level again. Renewed prosperity would simply spark the entire cycle, and, unfortunately, most would end up living in poverty once again. Malthus was very pessimistic about the evolution of society. He did not believe that the standard of living for the average person would continually improve.

The key to Malthus's theory is diminishing marginal returns (marginal product) to land and labor. There was little capital available and most production at the time was labor intensive. At first, Malthus argued, the best land would be used to produce food. As population expanded more food would be needed and this would require that more land be brought into production. However, diminishing returns to the land would eventually set in. In addition, diminishing returns to labor would also set in on a given amount of land. With population growth there would be more people working and eventually this would drive wages down. Gradually, population
growth would push the productivity of the land and labor to such a low point that most people would be living in poverty again. Malthus viewed this as the normal state of affairs.

To model this, consider a simple set-up where inputs of land (A) and labor (L) are used to produce an output, say wheat (Y). Denote the relationship between the inputs and the output, \( Y = F(A, L) \). This is a production function. It says that output is a function of the inputs of land and labor. To be sure there are other important inputs, however, we will abstract from them for the moment.

Suppose the amount of land available for production is absolutely fixed. In that case, the only way to increase output is by using more labor. An increase in labor will increase output. However, under diminishing marginal product, the extra output we get when adding more workers is less and less. At first, labor is very productive and the extra output we get, \( \Delta Y > 0 \), for a given increase in labor, \( \Delta L > 0 \), is a lot so the slope \( \Delta Y/\Delta L \) is a large number. (Remember \( \Delta Y/\Delta L \) is just the rise over the run, or the slope.) This corresponds to region A in Figure A where the slope of the production curve is steep. However, eventually, diminishing returns to labor will set in and the additional output we get when we add more labor diminishes so \( \Delta Y/\Delta L \) is a smaller number; the slope flattens out. This corresponds to region B where the slope is flatter.

One phenomenon that Malthus did not foresee was the industrial revolution. If scientific advancements improve the technology, this will alleviate diminishing returns to labor and also land. A simple way to model this is the following, \( Y = TF(A, L) \), where T represents the technology. An increase in T causes the production curve to swivel upward as in Figure B. Notice that the slope of the new curve becomes steeper as we move from region C to D. This captures the idea that labor becomes more productive as a result of technical innovation. The greater the productivity of labor, the higher the standard of living will be.

If there is a constant stream of technical and scientific innovation taking place, the standard of living might continually improve. In a strong sense, the industrial revolution was able to overcome diminishing returns. And, almost as if by magic, people chose not to produce more children when they experienced an increase in their standard of living in the mid 19th century. Indeed, England enjoyed a long period of relative peace and prosperity after the Napoleonic wars ended in 1815 after almost twenty-five years of constant warfare (1792-1815). The next eighty-five years saw only three brief wars, the Crimean War in 1853 – 56, and the first and second Boer Wars of 1880 - 81 and 1899 - 1902, and the longest sustained period of relative growth in Britain's history since the Middle Ages.
To be sure there were some economic downturns and much poverty. Recall that the novels of Charles Dickens were written during the middle of the 19th century and were a reaction to the abject poverty and cruelty many people suffered from. However, there was also tremendous opportunity as the economy grew at an enormous pace during the 19th century. Horse transport was replaced by railroads, modern methods of producing clothing, food, and products like steel were introduced and improved, and communication was dramatically improved with inventions like the telegraph and the laying of the transatlantic cable, which connected North America to Europe. It was somewhat ironic that Malthus made his pronouncement about most people living in poverty when he did, on the eve of this period of tremendous economic growth!

2.4.2 Growth theory of the 1930's: Knife-edge growth.
In the mid to late 1920's the demand for corporate stock increased and share prices rose dramatically in value. Everyone wanted to get into the stock market. Some saw it as an easy way to get rich quickly. At the time people could borrow to buy stock using little of their own money up front. In addition, shareholders were also personally liable for the debts of the companies they owned stock in. A creditor of a company could come after a shareholder's personal assets in repayment of the debts of the company. Then in October of 1929 the market crashed. Many investors were wiped out. Not only was their stock worthless, but they also had to repay the money they had borrowed to buy the now worthless stock. And creditors started suing individual shareholders for the debts of the companies they owned shares in. Many had their personal assets seized as a result. This ushered in the Great Depression.

In the summer of 1929 per capita GDP started falling, although this was not known until after the crash in October. Three series of bank failures occurred from 1929 to 1932 as the Depression deepened. The economy essentially collapsed during this period so growth was negative. The crash wiped out a lot of people so they cut back on their spending. As people reduced their spending, demand fell even more and firms had to cut back. As firms cut back, they laid off workers, and the downward spiral increased in intensity.

The growth of the economy seemed to be a tenuous and fragile matter. Economic analysts began to turn their attention to explaining this fragility. Not surprisingly, they developed a model where the growth of the economy was very fragile. These models are known as "knife-edge" models. In this sort of model, if the parameters like the savings rate and population growth rate are just right, growth occurs along a "knife's edge." However, if one single parameter like the saving rate is off, the economy will veer off the "knife-edge" into a depression. The leading advocates of this model were Roy Harrod and Evsey Domar. Their model relies on what has become known as the Leontief technology.

Let $Y = \text{output}$, $K = \text{capital}$, and $L = \text{labor}$. The Leontief technology is characterized by a production function of the following form, $Y = \min\{aL, bK\}$, where $a$ and $b$ are positive constants, and the notation $\{\}$ is set notation. Think of $K$ as machines. So $\{aL, bK\}$ is a set with the elements $aL$ and $bK$. This looks a bit strange but it's actually quite simple. Let's look at a special case first,

$Y = \min\{L, K\}$.

$\{L, K\}$ is a set with elements $L$ and $K$. The "min" means that $Y$ is equal to the minimum or smallest of the two arguments listed, either $L$, or $K$. If $L < K$, then $\min\{L, K\} = L$ and $Y = L$. If $L > K$, then $\min\{L, K\} = K$ and $Y = K$. If $L = K$, then $\min\{L, K\} = L = K$ and $Y = L = K$.

Example: $Y = \min\{L/3, K\}$. Suppose $L = 3$ and $K = 1$, then $\min\{1, 1\} = 1$ and $Y = 1$. Suppose $L = 5$ and $K = 1$. Now $\min\{5/3, 1\} = 1$ and $Y = 1$ so there is too much labor. With $K =$
1, you only need 3 workers, i.e., with one machine you need three workers, but you have 5 which is too many. Suppose \( L = 3 \) and \( K = 2 \). Then \( \min \{\frac{3}{3}, 2\} = 1 \) and \( Y = 1 \). Now, there is too much capital. Suppose \( L = 6 \) and \( K = 2 \). Then \( \min \{\frac{6}{3}, 2\} = 2 \), i.e., with two machines you need six workers, three on each machine.

More generally, \( Y = \min \{aL, bK\} \). In the previous example, \( a = \frac{1}{3} \) and \( b = 1 \). If \( aL < bK \), then \( \min \{aL, bK\} = aL \) and there is too much capital. If \( bK < aL \), \( \min \{aL, bK\} = bK \) and there is too much labor. There is just the right amount of capital and labor if \( aL = bK \).

Suppose this technology captures total or aggregate production for the whole economy. If \( aL = bK \), then the economy has just the right amount of labor and capital and both resources are fully employed (So the economy is on the PPF. Actually, the PPF is not a “frontier” but just one point. Can you figure out why?) Unfortunately, Harrod and Domar argued that the usual state of affairs was characterized by a capital shortage, or labor surplus, where \( aL > bK \). In that case there would be some unemployed labor and growth would begin to slow down; the economy would fall off the "knife's edge" of growth. They argued this explained the Great Depression.

Let’s illustrate this geometrically. Consider the situation depicted in the diagram for an individual firm. It uses capital and labor to produce an output according to \( Y = \min(3.334L, 10K) \), where \( a = 3.334 \) and \( b = 10 \). One machine (K) requires three workers (L) to operate it and it can produce ten thousand units a month. The L-shaped "curves" labeled \( Y = 10 \) and \( Y = 20 \) are called "isoquants." Every point on a given isoquant produces the same amount of output with different amounts of the two inputs. So on the \( Y = 10 \) isoquant, each of the three points A, B, and C are capable of producing \( Y = 10 \).

There is something special about this technology. Adding a machine without adding any workers, a move from point A to B, does not add any output. The extra machine is wasted without workers to run it. Adding three workers without buying a new machine, a move from A to C, also does not add anything to output. The extra labor is wasted. The only way to increase output is to buy a new machine and hire three additional workers to operate it, a move from point A to D. Inputs in this type of technology are complements; there is no substitution between labor and capital. It is thought that this type of technology characterizes heavy manufacturing.

An individual firm will never choose a point like B or C. Why? Adding units of a single input adds to the firm’s cost but will not add more output so profit is lower as a result. But what if this technology characterizes the entire economy? If this technology dominates most of the economy, then some resources will probably be unemployed unless the economy is endowed with resources in exactly the right proportion. This is why growth in this model is called “knife edge.” It only happens by accident, or fortuitous luck. Harrod and Domar, among others in the
1930's, thought there was **excess labor** in the economy and not enough capital, and so labor would experience a high degree of **unemployment**. This model seems to capture that.

This type of "growth" model reflected the **pessimism of the Depression era of the 1930's**. During the Great Depression of the 1930's output plummeted dramatically and the economy recovered only very slowly. Indeed, the economy had not fully recovered even by 1939, ten years after the start of the Depression. At one point 25% of the work force nation wide in the US was unemployed! It was really World War Two that ended the Great Depression. Governments began spending more in order to prepare for war in 1939. Building tanks, airplanes, and guns generates a tremendous amount of economic activity. Indeed, when the war was winding down in 1945, some thought the world would sink back into the Depression when governments began demobilizing their troops and started cutting their spending.

The late 1940's was also a period of tremendous labor strife as well. Many unions went on strike seeking better pay for their members. Some thought this would also wreck the economy. But it didn't. Why? The pent up consumer demand from the war years unleashed a tremendous increase in consumer spending in the 1950's and the US economy entered its greatest period of sustained economic growth since the early 1920's. Other economies also experienced extraordinary growth in this period. For example, both Germany (west) and Japan were able to rebuild their devastated economies by the 1960's. People were more optimistic about their future, aside from the implications of the Cold War.

### 2.4.3 Solow's (1956) Neoclassical Growth Model.

The optimism of the 1950's led to a new generation of models designed to study the growth process. In particular, Robert Solow's model described a smooth growth process that is not subject to the knife-edge problem. He was interested in explaining the sources of economic growth and his focus of attention was on capital and the capital accumulation process. His model revolutionized growth theory and eventually won him the Nobel Prize in Economics.

Solow argued that labor and capital can generally be substituted for one another in most production processes, as opposed to the "knife-edge" technology, where there isn't any substitution between inputs. Solow showed that the growth process would be more stable if some substitution between inputs is possible. However, eventually growth would slow down because of diminishing returns to physical capital. He also showed how important technological change could be in determining an economy's ability to continue growing.

Suppose there is unemployed labor. According to the knife-edge model this could cause growth to stop. However, if there is a surplus of labor, there will be downward pressure on the real wage. As the real wage falls, firms would be more likely to hire workers and substitute labor for capital. This allows growth to proceed in a "smooth" manner. The possibility of substitution between labor and capital is captured by a smooth, downward sloping isoquant, as opposed to the "L-shaped" isoquant of the Leontief technology.

Suppose the production function is given by

$$Y = \sqrt{LK}.$$  

We can graph this by fixing $Y$ and finding the different combinations of $L$ and $K$ that produce the fixed amount of $Y$. Fix $Y$ at $Y = 3$, then $3 = \sqrt{LK}$. Notice that $(L = 1, K = 9)$ can produce $Y = 3$, $(L = 9, K = 1)$ can produce $Y = 3$, and $(L = 3, K = 3)$ can produce $Y = 3$ so there is some substitution between labor and capital. If one input like labor is unemployed, its price will drop and firms will have an incentive to hire the now cheaper input. If there is substitution in the technology, then the firm will be able to produce the same amount as before but using more of the cheaper input, Labor, and less of the now more expensive input, Capital. This response
would tend to reduce the length of a recession and allow the economy to recover and grow once again.

We imagine there is a large number of consumers and firms in the economy. Consumers choose their consumption so as to make themselves as well off as they can subject to their budgets. Firms choose how much of each input to buy and how much to produce so as to maximize profit. Consumers supply inputs like their labor to earn income and then use the income to buy outputs. Firms purchase inputs like capital and labor and use them to produce output, which they then sell to get revenue. So firms and consumers are generally on the opposite side of both the input and output markets. In a general equilibrium, supply equals demand in each market at the going prices.

Let \( y = f(k) \), where \( y \) is output per worker and \( k \) is capital per worker. Let \( c \) = consumption per person, \( i \) = total business investment by firms per person, and \( g \) = government consumption per person. \( g \) includes items governments buy like missiles, paper clips, $700 claw hammers, forms and red tape. It doesn't include transfer payments like social security or welfare. And you can think of \( y \) as per capita GDP. The following equation is the spending equation,\

\[ y = c + i + g, \]

where \( y \) is total production or income per worker and \( c + i + g \) is total spending by consumers, firms, and government. The spending equation says simply that all income generated by the economy \( y \) is spent by someone in the economy \( (c, i, \text{or } g) \). For simplicity, we will ignore government spending for the moment, \( g = 0 \).

What is consumption? This is consumer demand for all goods and services in the economy rolled up into one variable for simplicity's sake. Solow assumed that consumption was proportional to income, following John Maynard Keynes,

\[ c = mpc(y), \]

i.e., \( mpc \) times income, where \( mpc \) = marginal propensity to consume out of a dollar, i.e., it is the extra amount you consume out of a dollar, and \( y \) is income. This is known as a Keynesian consumption function. If \( mpc = \frac{3}{4} \), then \( c = (3/4) \cdot y \). And \( 1 = mpc + mps \), where \( mps \) = marginal propensity to save.\(^3\) We can combine the last two equations to get, (for \( g = 0 \)),

\[ y = mpc \cdot y + i. \]

What is business investment? It is composed of several items. First, there are firms that are investing in new capital equipment so the stock of capital changes, \( \Delta k > 0 \). Second, there are firms that are replacing worn out machinery and equipment that has depreciated, \( dk \), where \( d \) is the depreciation rate. Third, there are firms that are expanding and hiring new workers who must

---

\(^3\) Later we will develop the theory behind why consumers might choose their general consumption like this.
be equipped with capital in order for them to produce, \( nk \), where \( n \) is the growth rate of the work force. So for investment we have,

\[
i = \Delta k + dk + nk.
\]

Substitute this into the previous equation to get

\[
y = \text{mpc}(y) + \Delta k + dk + nk = \text{mpc}(y) + \Delta k + (d + n)k.
\]

Solve for \( \Delta k \) and divide by \( k \) to get the following version of Solow's famous equation, which is all you really need to remember:\(^4\)

\[
\frac{\Delta k}{k} = mps \frac{f(k)}{k} - (d + n),
\]

where \( mps = 1 - \text{mpc} \) is the marginal propensity to save, and \( y/k = f(k)/k \) is average output. This is Solow's fundamental equation of growth theory. Calculate average output, multiply by the mps, subtract population growth and depreciation, and the result tells you how capital will grow.

Recall that \( \Delta X/X \) is the definition of the growth rate, so \( \Delta k/k \) is the growth rate of capital per person available for production in the economy. And if \( \Delta k/k > 0 \) so capital is growing, then output and consumption are also growing. Why? If \( k \) grows, then \( y \) grows because \( y = f(k) \), and if \( y \) grows, then \( c \) grows because \( c = \text{mpc}(y) \). On the other hand, if \( \Delta k/k < 0 \), then growth in capital is negative so \( y \) and \( c \) are both falling. We say the standard of living is improving if consumption is increasing.

Example: suppose \( y/k = 3 \), \( mps = .1 \), \( d = .1 \), \( n = 0 \). Then \( \frac{\Delta k}{k} = (1)(3) - .1 = .2 \)

Example: suppose \( y/k = 3 \), \( mps = .2 \), \( d = .1 \), \( n = 0 \) so people are saving more at the margin from each dollar they earn. Then \( \frac{\Delta k}{k} = (.2)(3) - .1 = .5 \), and the increase in savings increases the growth rate.

Example: suppose \( y/k = 3 \), \( mps = .1 \), \( d = .1 \), \( n = .1 \) so the population growth rate is higher but people are saving as in the first example. Then \( \frac{\Delta k}{k} = (.1)(3) - .2 = .1 \), and the growth rate falls when population grows faster.

What Solow's equation says is that the growth rate of capital per person is determined by the marginal propensity to save, average output \( (y/k) \) or \( f(k)/k \), depreciation, and population growth. In many advanced economies total consumption per person is about 67% of income so the \( mpc = 0.67 \) and the mps is then \( mps = 0.33 \). Depreciation of capital equipment is about 10%, so assume \( d = 0.10 \). And population growth in Europe, Canada, the US, and Japan is almost zero, so let \( n = 0 \). If \( y/k = 0.3636 \), Solow's equation (*) implies

\[
\frac{\Delta k}{k} = (.33)(.3636) - 1 = .02,
\]

which is close to the average growth rate in the US since World War Two. Since \( k \) is growing, \( y \) and \( c \) must also be growing.

This is how we measure the increase in our standard of living. If the average person can consume more, she is better off. The growth rate will increase if people save more at the margin, if there is greater average output, or if depreciation and population growth are lower.

\(^4\) The last several paragraphs are a derivation of Solow's famous formula. You don't need to know the derivation, only the formula.
Solow’s equation is rather complicated. To simplify, we can graph it to study the determinants of economic growth. The easiest way to do this is to break the equation into two parts and graph the two parts separately. Let A and B represent the two parts of the equation according to,

\[ A = \text{mps}(k)/k \]
\[ B = d + n. \]

By using these definitions, we have the following version of the equation, which states that the economy’s growth rate is equal to the difference between two numbers, A and B,

\[ \Delta k/k = A - B. \]

For example, if A = 5% and B = 2%, then the growth rate is \( \Delta k/k = 5 - 2 = 3\% \). As another example, if A = 3% and B = 8%, then the growth rate is negative, \( \Delta k/k = -5\% \) and the economy decays instead.

How do we graph these two parts, A and B? Recall from ninth grade algebra that we can graph any equation of the form \( Y = F(X) \) by putting \( X \) on the horizontal axis and \( Y \) on the vertical axis. Take the first relationship, \( A = \text{mps}(k)/k \). Let \( A \) play the role of \( Y \), let \( \text{mps}(k)/k \) play the role of \( F(X) \), and let \( k \) play the role of \( X \). It turns out that \( \text{mps}(k)/k \) is very complicated. However, if there are first increasing marginal returns (see section 2.3) for low values of \( k \) followed by diminishing marginal returns for higher values of \( k \), the A-curve will look as it is depicted in the first graph on the left below.

Next, examine the second part, \( B = d + n \). Now \( B \) plays the role of \( Y \), and \( d+n \) plays the role of \( F(X) \). However, \( k \) does not appear in this equation so there is no variable like \( X \) in it. The sum \( d+n \) is just a number or constant. So this says that the \( Y \)-value, or \( B \) in this case, is constant. The graph of such a constant is a straight horizontal line as depicted in the middle diagram as the B-line. The two graphs are combined on the far right.

The Geometric Solow Model

When \( A > B \) at a given level of \( k \), capital is growing, hence the economy is growing and the average person’s consumption is increasing. When \( A < B \) at a given level of \( k \), the economy decays and consumption falls. When \( A = B \), the economy stops growing. The gap between the two "curves" at any level of \( k \) is the growth rate of capital per worker, \( \Delta k/k \). The growth rate is positive if \( A > B \), it is negative if \( A < B \), and it is zero if \( A = B \).
Consider an example. Suppose the economy starts out at $k_1$ at time $t = 1$ in the diagram above and suppose $y/k = 16$, $\text{mps} = 1/4$, $d = 1$, and $n = 1$. Then $A = 4$, $B = 2$ so the growth rate in capital per worker at $t = 1$ is 2. This is depicted as the vertical gap between points $a$ and $b$ in the diagram at the level of capital $k_1$. Since $a' > b$ at $k_1$, capital is growing so capital in the second period, $k_2$, is larger than $k_1$ and we move to the right on the horizontal axis from $k_1$ to $k_2$. Since $a' > b'$ at $k_2$ the economy is growing and it will shift to the right again. But notice something important. The gap $a' - b'$ is larger than the gap $a - b$. This means the growth rate at $t = 2$ is greater than at $t = 1$. The economy is growing faster. Isn’t this goods news?

This will continue until we reach $a^*$, which is the maximum growth rate. After that the economy continues to grow but at a slower pace. Eventually the economy will converge to the level $k^*$ and growth will stop in the long run (because $A = B$ at $k^*$). We should note that many economies appear to grow very rapidly at first after some technological innovation, e.g., railroads. However, the data suggests that eventually the growth rate will slow down. This was true for the UK, the US and Japan as well. Japan enjoyed phenomenal growth in the 1970s and 1980s. However, they experienced a real estate bubble that caused their economy to go into a severe recession and they experienced the so-called lost decade of the 1990s. The Solow model appears to give us a very good explanation of the growth process.

Why does this happen? Why does economic growth slow down? How does this model explain that? It is the shape of the $A$ curve that causes the problem. The $A$ curve has its shape because eventually diminishing marginal returns to capital per worker set in. But this is almost exactly the same argument made by Malthus two hundred years ago!

How does technological progress affect this? In the diagram below the economy is converging to the capital per worker $k^*$ where curve $A$ intersects with line $B$. Suppose after 23 years we are at points $a$ and $b$ in the diagram and the growth rate (the gap between $a$ and $b$ in year 23) is slowing down. However, if there is a significant technological innovation, the $A$ curve will shift to the right (to the dashed curve) and the growth rate of the economy will begin to increase after $a'$. The economy will converge to the new level of capital $k^{**}$, where $A' = B$. The growth rate is now higher as the economy follows the dashed $A'$-curve. However, diminishing returns will eventually set in again so the growth rate will begin to decrease as we get closer to $k^{**}$. Also, notice that $y^* = f(k^*)$ but after the innovation $y^{**} = f(k^{**})$. Since $k^{**} >
$k^*$, $y^{**}$ is larger than $y^*$, and $y^{**}$ is the new, higher standard of living! People are better off after the innovation on average.

(You can also ask yourself what happens if the population growth rate of new workers, $n$, increases. How will this affect the growth rate? Basically, it will shift the B line upward. Now compare two countries alike in every respect except that in economy #1 the population growth rate, $n$, is low ($n = 1\%$) and in economy #2 $n$ is high ($n = 3\%$). We can model this as a shift upward in the B line. Which economy will grow faster?)

What can we conclude on the basis of the Solow model? Compare two economies that are the same in every regard except one has a lower willingness to save and hence a lower mps. The Solow model predicts that that economy will have a smaller growth rate. An economy experiencing large population growth will also have a lower economic growth rate. And an economy where government takes more out of the economy will also have a lower economic growth rate, although this is somewhat tentative since we have not included a positive role for government to play in the model. Finally, we can also conclude that technological progress can overcome diminishing returns, and, more specifically, diminishing marginal product of capital, if the technology keeps improving.

Another issue that has arisen recently is whether poor countries will eventually catch up to rich countries. Return to the original Solow Equilibrium diagram. A country that begins growing at rate $a-b$ and then rate $a'-b'$ will experience a growth rate that is increasing but then eventually decreasing. Growth will slow down until $k^*$ is reached.

What about a poor country that comes along later? It will follow the same path if it has the same technology and will grow more quickly. One can imagine a rich country at $a'$-$b'$ and a poor country at $a$-$b$. When the rich country's growth rate starts to slow down, the poor country may start to grow faster. The simple version of the Solow model predicts that it will eventually converge to the same position as the rich country. This is known as absolute convergence. The empirical evidence does not confirm this. However, if technology, savings behavior, and population growth differ across countries, each country may converge to its own $k^*$. If countries
are converging like this, it is called **conditional convergence** because it is conditional on the country’s unique circumstances, e.g., mps, n. There is strong evidence that supports this.

### 2.5 New Theories of Economic Growth

There has been a lot of research on the determinants of growth in the last thirty years including human capital, knowledge spillovers, and public infrastructure, among others. Some of the new theories lead to this diagram where there is growth in the long run at \( a^{++} - b^{++} > 0 \). Notice that growth increases between \( a - b \) and \( a^* - b^* \) as the economy moves to the right in the diagram. The growth rate is falling as the economy moves from \( a^* - b^* \) to \( a^+ - b^+ > 0 \). However, eventually there is a constant gap between curves A and B as the economy moves from \( a^* - b^* \) to the long run growth rate at \( a^{++} - b^{++} \). This means that eventually the growth rate settles down to a positive constant, e.g., 2%, rather than zero as in Solow’s model. Human capital, knowledge, and public infrastructure overcome diminishing returns in the long run to produce growth in the long run.

Some economists think that cutting taxes on capital income will improve growth. We can model this by shifting the A curve up. If true, what do you think this will do to growth in the long run?

#### 2.5.1 Human capital investment

Recent research on economic growth has placed greater emphasis on human capital development as embodied in education and training. Greater human capital can spur economic progress by improving the quality of the labor input. If workers are smarter, better trained, and simply know more, they can solve problems more efficiently, manage more effectively, make suggestions that improve productivity, and they can operate more complicated machinery, which allows designers to design even more complicated equipment. As a result, economic growth increases. This has been studied and worked out in detail by Paul Romer and Nobel Laureate Robert Lucas, among others.

Consider the following technology, \( Y = F(K, HL) \), where \( Y = \) output, \( K = \) physical capital, \( H = \) human capital of skilled workers, \( L = \) hours worked. In that case, growth in \( H \) may overcome diminishing marginal product of \( L \) and growth need not eventually stop. In fact, we can experience growth in per capita magnitudes \( Y/L, K/L, \) and \( H/L, \) which will generate growth in consumption \( c. \) Essentially, diminishing returns in each input when taken separately can be overcome by growth in all inputs. Remember Malthus thought the stock of land was ultimately fixed and this is what caused diminishing returns to labor to set in. In Solow’s model the quality
of the work force is fixed so diminishing returns to capital per worker eventually set in. But if all inputs are growing, namely, K and HL, then the economy may continue growing as well.

2.5.2 Knowledge as a public good
Another new theory due to Paul Romer involves the accumulation of new knowledge. Knowledge has two effects. First, it directly improves the productivity of the firm that creates the new knowledge. Second, once the knowledge has been created, other firms can study it and benefit from it as well as long as the knowledge becomes publicly available. So knowledge can "spill over" to other firms. So \( Y = F(K, L, R) \), where R is research that spills over to other firms. Growth in R can overcome diminishing returns to cause growth in the long run.

Research and development produce new knowledge and this can affect production making it more efficient by finding new ways of doing things and it can lead to new and better products. So if one firm acts as a pioneer and shows that some new technology or some new way of conducting business can cut cost, other firms can learn from this experience and lower their costs as well. Examples include standardized and interchangeable parts introduced in the 1850's in the manufacture of rifles, the automobile assembly line of Henry Ford, a hub and spoke transportation network like Federal Express pioneered, or advertising on the Internet. Growth in the stock of knowledge and knowledge "spillovers" to other firms, can overcome diminishing marginal product of capital.

However, there may be two problems with this. First, some knowledge is carefully controlled by patents and copyrights and cannot spill over to other firms. Second, if most of the benefits from the new knowledge spill over to other firms, the firm that creates the knowledge has no incentive to innovate and create the knowledge in the first place. It will innovate only if it benefits from doing so. So there is probably too little basic research created by the market system. This is one area where the government can usefully promote growth by helping students overcome high unaffordable interest rates by subsidizing their borrowing.

2.5.3 Public infrastructure
Yet another new theory emphasizes the value of public infrastructure. Economic progress truly depends on public infrastructure like roads, bridges, highways, airports, rail track, harbors, fiber optic cables, cell phone towers, satellites, and so on. Better infrastructure reduces transport costs and this makes it cheaper to ship freight, for example. Better transportation networks in urban areas will make it easier for commuters to get to work, as another example. David Aschauer has pioneered research on this issue and that work indicates that infrastructure has a strong effect on GDP. Unfortunately, the US began reducing its investments in public infrastructure in the last twenty years or so. This may have caused growth in labor productivity to slow down.

Let G be public infrastructure. The production function is now given by \( Y = F(L, K, G) \) and an increase in G can swivel the production curve upward much like technological progress does. Thus, public infrastructure or public capital can improve the productivity of the private inputs. Aschauer tried to estimate the impact of each input L, K, and G on US output Y from the late 1940s to the mid 1980s. He discovered that public capital had a significant impact on the US economy’s output Y as measured by real GDP. A 10% increase in public capital causes at least a 2.5% to 3.9% increase in GDP. Growth in productivity has declined since about 1970. Aschauer was able to show that most of this decline was due to the decline in spending on public capital. Later research confirmed that public capital had a significant positive effect albeit it was somewhat smaller than Aschauer’s initial estimate.

This is critically important since the US and other countries have been letting infrastructure investments slide since the mid 1990s. Over 70,000 bridges, or about 11% of all bridges, in the
US are under restricted use. This means that the heaviest trucks cannot use them. Why is this important? Consider a firm that produces something and has to ship it from where it is produced to its market. It hires a trucking company that specializes in transporting goods. Suppose that firm chooses the optimal cost minimizing route, which takes it over a bridge and uses its heaviest trucks. This is the optimal decision that minimizes the firm’s costs. Later, suppose engineers find cracks in the bridge and restrict the use of a bridge. So the trucking firm has a choice: use smaller trucks or find a different route. Either way, its costs increase. Why? Because the first route was cost minimizing; other routes will be more costly and using smaller trucks will be more costly. It will pass along some of this increased cost in higher shipping prices, which eventually will get passed along to consumers. This is basic microeconomics!

**Application:** Amazon ships a huge number of packages each day. They have pioneered “smart” ordering/shipping systems to automate this process. If infrastructure begins to wear out, shipping will become more expensive, and this will raise Amazon’s cost. Part of this increased cost will be put off onto customers in higher prices. Perhaps, this is why CEO Jeff Bezos is proposing a system of drone deliveries.

**Application:** Under "just in time" (JIT) inventory system firms do not maintain inventories in warehouses. Instead, the parts the firm needs for production are shipped from their suppliers just before production takes place and the firm ships its output when it is needed by their customers. This minimizes the inventory it has to keep on hand. One problem with this system is that it requires an efficient transportation network that can always deliver goods on time. Japanese companies pioneered this type of system. Unfortunately, firms in Tokyo discovered that congestion, bottlenecks, and inefficient street networks in the city of Tokyo made "just in time" deliveries very difficult and costly. Thus, a poor transportation network, or congestion problems, can reduce the productivity of the JIT system and hence the productivity of the private sector. This may be impossible to overcome in a large city like Tokyo or New York.

### 2.6 The empirical evidence on growth

What does the growth rate depend on? There have been numerous studies that have attempted to answer this very question. A number of determinants have been uncovered. These include public capital, openness to trade, political stability, rule of law, corruption, and human capital.

**Openness to trade** captures the idea that countries that are more open to trade will import goods that are hard for the local firms to produce and export goods that local firms are good at producing. This is the Invisible Hand theorem in an international context.

Is the **rule of law** respected? If property rights are carefully defined and enforced, then people will accumulate wealth. They will start businesses and borrow to invest in factories and equipment and this will create jobs. They will save and accumulate assets, and this will provide funds for banks to loan out. If laws are not enforced, none of this will happen and the economy will stagnate.

The more stable a country is politically the less uncertainty there is for investors. If the government is constantly in turmoil, people do not know what policies will be pursued in the future. This makes it difficult for them to plan for the future. Investors can be very conservative and difficult to convince. After all, they are putting their funds on the line. If they believe a new government will come along and impose high taxes on their investments in the future, they will choose not to invest and this will hurt the growth rate.

Obviously **corruption** can be a difficult problem to solve. If people can get ahead by bribing an official, then they will spend time and resources seeking political favors and this is not a productive use of society’s resources. And merit will not be rewarded. In some countries one can become a general in the army, for example, if one pays enough of a bribe, or comes from a
family that is influential. Now imagine that country goes to war. Since generals became generals not through ability but through political connections and bribes, it would not be surprising if they lost the war. It would also not be surprising to find that companies that survived because of bribes would not be as competitive and productive as they would be otherwise without the bribes.

Both public capital and human capital have been found to have a positive influence on growth. In particular, secondary and tertiary education are particularly important.

Finally, some researchers have found a link between inequality and economic growth, although this remains controversial. The idea is that the more unequal the income distribution is, the lower the growth rate will be. For example, if the poor have difficulty getting loans it will be harder for them to pay for school, complete their training, or start a business. This would tend to shift income toward the top of the income distribution. So by pursuing policies that improve the income distribution by redistributing to those with lower incomes, society might be able to also increase the growth rate of the economy.\footnote{This is controversial. Forbes (American Economic Review, 2000) found no connection between inequality and growth for a sample of 45 countries.}

2.7 The Capital - skilled labor complementarity hypothesis

Zvi Griliches in an important paper published in 1969 posited that private capital and skilled labor are complements in production, while private capital and unskilled labor are substitutes. He provided some evidence in support of this idea for the US.

The idea is a simple one actually. Suppose production occurs according to \( Y = F(K, S, U) \) where \( S \) is skilled labor, \( U \) is unskilled labor, and \( K \) is capital. As the capital stock grows over time, there is an increase in demand for skilled labor because the two are complementary to one another; greater demand for one increases the demand for the other. However, capital and labor that is unskilled may be substitutes. So as capital grows over time, there is less need for unskilled labor and its demand falls.

Now ask what happens to wages. If the demand for skilled labor is increasing, the wage of skilled workers will increase. If the demand for unskilled labor is falling, its wage will also be falling. Now calculate the so-called skilled wage premium, the ratio of the skilled wage to the unskilled wage. It will be increasing over time. Let \( v = \) skilled wage, \( w = \) unskilled wage. The skill premium is the ratio \( v/w \). Since the demand for skilled labor is increasing, \( v \) will be increasing and this increases the premium. And since the demand for unskilled labor is falling, \( w \) is falling which also increases the ratio \( v/w \).

As this process continues skilled workers experience an increase in income, while unskilled workers see a decline in their income. This is one explanation for the increase in income inequality in the last thirty years; skilled workers are becoming wealthier, while unskilled workers are becoming relatively poorer, as capital accumulates.\footnote{See the evidence presented by Goldin and Katz (Quarterly Journal of Economics, 1996) and Krusell, Ohanian, Rios-Rull, and Violante (Econometrica, 2000).}

2.8 One Final Point: The Computer Revolution

Computers and high tech goods have become much more common place since 1980 especially in heavy industry but also in retailing and design and service industries. Why then did growth in worker productivity not increase in the late 1980s or even early 1990s? From 1985 to 1995, over 80 million PC's and Macintosh computers were sold in the US. Everywhere we look we see computers changing our lives. They appear to be ubiquitous, from robotized and computerized
production lines to ATM's, from the dashboards of our cars to home heating systems, from our watches to our television sets and smart phones. They are in our schools, our workplaces, and even in the checkout lanes at the grocery store! Surely we must be more productive now because of all this new technology. Right? It was only in the last five years of the 1990s that productivity appeared to improve. Why did it take so long for the computer revolution to have an impact?

In an article in The New York Times (October, 1997) it was pointed out that growth in productivity since 1990 had not increased but had actually declined slightly (from 1990 to 1994). In fact, productivity growth actually declined from the early 1980's to 1995 to only about 1.1% each year, which is down from the 2.5 - 2.7% growth we experienced in the 1960's. How can this be with all this computer technology? Alan Blinder and Richard Quandt, economists at Princeton, wrote an article in the Atlantic Monthly (Nov, 1997) suggesting several reasons for the apparent disparity.

First, people who are thrown out of work by computers need to find other jobs. This may require them to retrain and this can take some time. Second, computer systems, as we all know, crash from time to time and this can lower productivity. Third, security is also a problem with computers. Anyone who has run into a computer virus knows full well how much havoc they can wreak and how much it can cost to deal with it in terms of lost time and work effort. Fourth, much time can be wasted while searching for something on the Internet. Even when you do a well-defined search on a "search engine" it can bring up 21,934 items. How long does it take for you to decide on the information you really need? Thus, we may be suffering from information overload. Fifth, computers are really nothing new. We have experienced innovations before this like the steam engine, railroads, and automobiles. In fact, other innovations, e.g., electricity, Henry Ford's assembly line, airplanes, and nuclear power, may have had a greater impact on growth and productivity than computers. Sixth, how much time does one waste playing computer games at work or sending silly texts to friends? (Of course, that doesn't happen at a university.)

It would appear that the growth in worker productivity of the late 1990s ended by the early 2000s, perhaps because of the dot-com crash. It is possible that the growth experience of the 1960s and the late 1990s is the unusual phenomenon and maybe the slow growth of the 1970s, 1980s, and 2000s is more the norm than not. Maybe, diminishing marginal returns is more of a driving force than even Malthus reckoned.

2.9 Conclusion
We have studied the concepts of production, diminishing marginal returns (or diminishing marginal product) and applied them to economic growth. Economic growth is one of the most important economic phenomena. If an economy is expanding over time the standard of living improves. Longevity increases, education expands, the productivity of the workforce increases, new products are being developed and brought to market, and the quality of life improves. Just the opposite may occur if the economy is contracting instead.

Diminishing returns are almost universal. The first hour you spend studying your lecture notes is very productive and you learn a lot. The second hour is productive to be sure, but not nearly as productive as the first hour. By the fourth or fifth hour you are becoming fatigued and your productivity may fall dramatically. The same is true of most human activities, e.g., jogging, eating, playing video games, watching all the Transformer movies back to back late at night and falling asleep half way through the second movie. This is an old idea in economics, first applied to economic growth by Thomas Malthus two hundred years ago.

Technological innovation and the widespread development and application of science are the main phenomena that can overcome diminishing returns. If there is a constant stream of scientific innovations coming along, the existing inputs like labor can experience improved
productivity over time. This can fuel further economic progress that allows the economy to continue growing. However, it appears that diminishing returns will eventually set in once again.

Why is this important to a person going into business? It is much easier for a firm to compete if the economy is growing than not. And the more rapid the growth, the easier it gets to survive in business. As we will see, with growth, incomes rise and people spend more on certain goods like travel, hotels, cruises, and air travel, which fuels growth in these industries.

Appendix
(This is just for the mathematically curious. Don’t worry about it.)
We will model government activity in the simplest possible way and see how the growth rate is affected. Consumers pay taxes and the government uses the taxes to spend on goods and services. The spending equation in Solow’s model is given by $y = c + i + g$, as defined in the text. Consumers maximize their satisfaction subject to their income constraint. Out of that process comes the consumption function, $c = mpc(y - t)$, where $y$ is income and $t$ is taxes so $y - t$ is disposable income. Firms choose their investment optimally to maximize profits. Investment is $i = \Delta k + nk + dk$, i.e., new machines, plus machines to equip new workers due to population growth, plus new machines to replace depreciated, worn out machines. Substitute for consumption and investment into the spending equation,

$$y = mpc(y - t) + \Delta k + (d + n)k + g,$$

gather terms in $y$ on the left,

$$y - mpc y = \Delta k + (d + n)k + g - mpc t$$

and simplify,

$$(1 - mpc)y = \Delta k + (d + n)k + g - mpc t$$

$$(1 - mpc)y - (d + n)k - g + mpc t = \Delta k$$

rearrange and divide by $k$,

$$\frac{\Delta k}{k} = \frac{(1 - mpc)y}{k} - (d + n) - \frac{g}{k} + mpc \frac{t}{k}$$

and since $mps = 1 - mpc$,

$$\frac{\Delta k}{k} = mps \frac{y}{k} - (d + n) - \frac{g}{k} + mpc \frac{t}{k}$$

To obtain the equation without government studied in the text, set $g = t = 0$. An increase in government spending reduces the growth rate since $g$ in this mode is not productive. An increase in the tax reduces consumption.

Let's do some examples. In an advanced economy, $mps = .33$, $d = .10$, and $n = 0$. If $y/k = .5$ and $g/k = .1$, then $\Delta k/k = .032$, which is slightly on the high side, but might represent the 1960's. Let's see how a drop in the mps, an increase in population growth, or an increase in government spending affects the growth rate in turn. First, suppose people save less so the mps = 0.25 and $d = .10$, $n = 0$, $y/k = .5$, and $g/k = 0.10$. Then $\Delta k/k = 0$ and growth stops! Second, suppose instead that population growth increases to $n = 0.10$, and $mps = 0.33$, $d = 0.10$, $y/k = .5$, and $g/k = 0.10$. Then $\Delta k/k = -0.068$ and growth is negative! Finally, suppose $g/k = 0.125$, and $mps = .33$, $d = .10$, $n = 0$, and $y/k = 0.50$. Then $\Delta k/k = 0.02375$, which is lower than $\Delta k/k = .032$. 

Important Concepts
The growth rate
Data on growth: what are the facts
Explaining the data: Traditional theories of growth
   Malthus
   Knife-edge growth
   The Leontief technology
   Solow's model of growth
New theories
   Human capital
   Knowledge spillovers
   Public infrastructure
   What did Aschauer find?
Empirical evidence on growth
The capital skilled labor hypothesis
   What did Griliches assert?
The computer revolution

Review Questions
1. Define the growth rate. What happens to the short term growth rate if the economy experiences a recession?
2. What does the recent empirical evidence on growth suggest?
3. What is diminishing returns? Define it. What is held constant in the definition?
4. Explain Malthus's theory of economic growth. How is it still relevant today?
5. How does Solow's model of growth differ from Malthus's?
6. What is Paul Romer's new theory of growth?
7. Explain how public capital can affect economic growth.
8. What are the latest theories of growth? Can you explain each one?
9. What does the empirical evidence tell us about political stability, corruption, and growth?
10. Has computer technology affected the long run growth rate?

Practice Questions
1. Under Malthus's theory of economic growth,
   a. growth continues unabated after a technological innovation.
   b. growth continues to accelerate after a technological innovation.
   c. growth continues unabated after a technological innovation because international trade increases after the innovation.
   d. growth eventually decreases after a technological innovation because people have more children that eventually compete in the labor market thus driving wages and the standard of living down.
2. The economy grew at a 3.7% rate in the fourth quarter of 1997 and a 4% rate during the first quarter of 1998. This means the productivity slowdown is over.
   a. True. The long run growth rate must be higher after two quarters of growth.
   b. False. We cannot tell whether growth has increased after only two quarters.

3. How does Romer's model of growth based on knowledge spillovers differ from Solow's model?
   a. They don't differ; they are merely two ways of saying the same thing.
   b. Growth eventually stops in both models but stops sooner in Solow's model
   c. Growth eventually stops in Solow's model but need not stop in Romer's model.
   d. Growth eventually stops in Romer's model but need not stop in Solow's model.

4. What would happen if the government reduced the tax on capital gains?
   a. Nothing.
   b. Wealthy people would get wealthier.
   c. People will accumulate more capital and growth will increase in the short term and possibly in the long run as well.
   d. People will accumulate less capital and growth will increase in the short term and possibly in the long run as well.

5. What happens when the population growth rate increases in the Solow model?
   a. The A curve shifts up causing the growth rate to increase.
   b. The A curve shifts down causing the growth rate to fall.
   c. The B line shifts down causing the growth rate to increase.
   d. The B line shifts up causing the growth rate to fall.
Answers
1. d.
2. b. The productivity slowdown involves the long run growth rate of the economy. Two quarters of data on GDP is not enough to allow us to conclude anything about the trend in the growth rate.
3. c. The A curve can flatten out to a horizontal line in Romer's model under certain conditions implying that growth can continue even in the long run in his model.
4. c.
5. d.