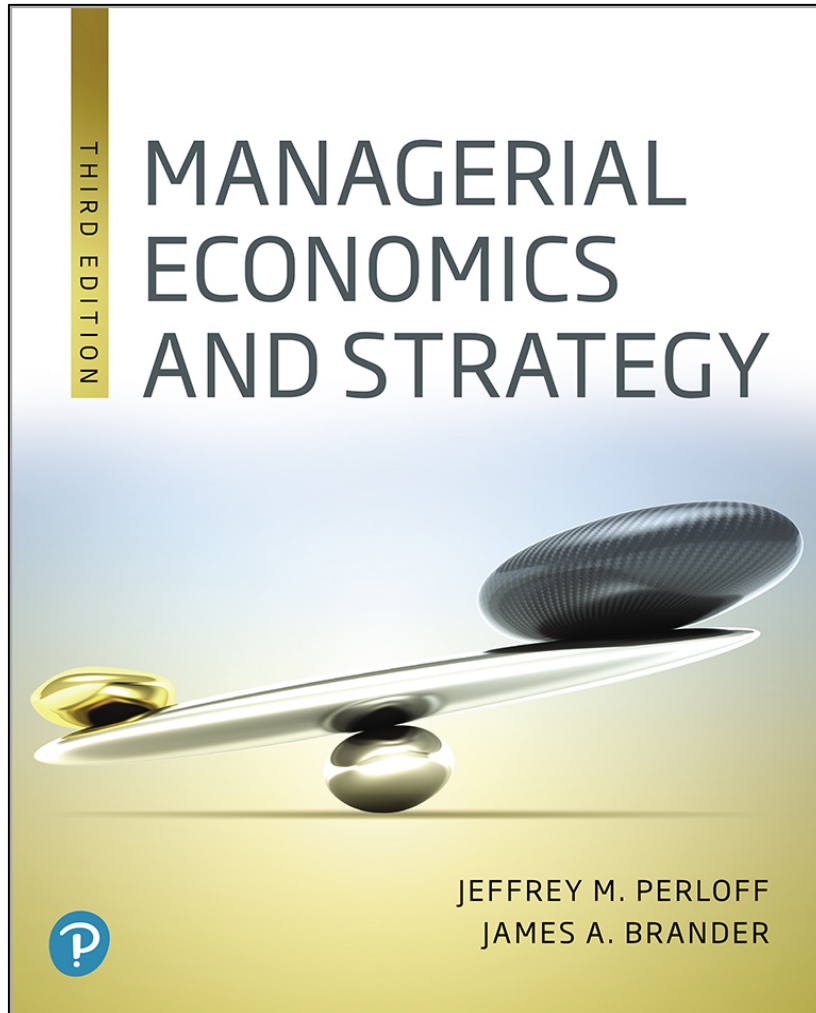


Managerial Economics and Strategy

Third Edition



Chapter 5

Production

Managerial Problem

Labor Productivity During Recessions

- How much will the output produced per worker rise or fall with each additional layoff?

Solution Approach

- First, a firm must decide how to produce. Second, if a firm wants to expand its output, it must decide how to do that in the short and the long run. Third, given its ability to change its output level, a firm must determine how large to grow.

Empirical Methods

- A **production function** summarizes how a firm converts inputs into outputs using one available technology. It helps to decide how to produce.
- Increasing output in the **short run** can be done only by increasing variable inputs. In the **long run**, there is more flexibility.
- The size of a firm depends on **returns to scale**. Its growth is determined by increments in **productivity** that comes from **technological change**.

Learning Objectives (1 of 2)

5.1 Production Functions

Use a production function to describe the relationship between inputs and output

5.2 Short-Run Production

Predict the effects of short-run changes in labor on output

5.3 Long-Run Production

Explain the long-run trade-off between labor and capital in production

Learning Objectives (2 of 2)

5.4 Returns to Scale

Determine whether a production function has decreasing, constant, or increasing returns to scale

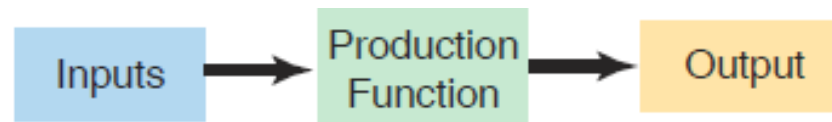
5.5 Innovation

Describe the effects of innovation on production

5.1 Production Functions (1 of 2)

Production Process

- A firm uses a **technology** or **production process** to transform **inputs** or **factors of production** into **outputs**.
- Inputs
 - Capital (K)—land, buildings, equipment
 - Labor (L)—skilled and less-skilled workers
 - Materials (M)—natural resources, raw materials, and processed products
- Output
 - It could be a **service**, such as an automobile tune-up by a mechanic, or a **physical product**, such as a computer chip or a potato chip.
- Production function



5.1 Production Functions (2 of 2)

- The production function summarizes ways inputs $\Rightarrow$ output
 - Maximum quantity of output that can be produced with different combinations of inputs, given current knowledge about technology and organization.
 - A production function shows only **efficient production processes** because it gives the maximum output.
- Production Function: $q = f(L, K)$
 - Production function for a firm that uses only labor and capital.
 - q units of output (wrapped candy bars) are produced using L units of labor services (hours of work by assembly-line workers) and K units of capital (number of conveyor belts).
- Production Functions, Time and Variability of Inputs
 - **Short run**: a period of time where at least one factor of production cannot be varied. Inputs can be **fixed** or **variable**.
 - **Long run**: period of time that all relevant inputs can be varied. Inputs are all variables.

5.2 Short-Run Production (1 of 5)

- The short-run is a period in which at least one input is fixed. In the context of a production process with only capital and labor as inputs, we assume that capital is fixed and labor is variable.

The Total Production Function: $q = f(L, \bar{K})$

- Relationship between output q and labor L when a firm's capital K is fixed
 - In Table 5.1, capital is fixed to 8 fully equipped workbenches. As the number of workers increases, so does output: 1 worker assembles 5 computers in a day, 2 workers assemble 18, 3 workers assemble 36, and so forth.

The Average Product of Labor: $AP_L = q / L$

- The ratio of output to the amount of labor used to produce that output
 - Table 5.1 shows that 9 workers assemble 108 computers a day, so the average product of labor for 9 workers is 12 ($=108/9$) computers.
 - Ten workers can assemble 110 computers in a day, so the average product of labor for 10 workers is 11 ($=110/10$) computers.
- Thus, increasing the labor force from 9 to 10 workers lowers the average product per worker.

Table 5.1 Total Product, Marginal Product, and Average Product of Labor with Fixed Capital

Capital, $\bar{K}$	Labor, L	Output, Total Product of Labor q	Marginal Product of Labor, $MP_L = \Delta q / \Delta L$	Average Product of Labor, $AP_L = q / L$
8	0	0		
8	1	5	5	5
8	2	18	13	9
8	3	36	18	12
8	4	56	20	14
8	5	75	19	15
8	6	90	15	15
8	7	98	8	14
8	8	104	6	13
8	9	108	4	12
8	10	110	2	11
8	11	110	0	10
8	12	108	-2	9
8	13	104	-4	8

Labor is measured in workers per day. Capital is fixed at eight fully equipped workbenches.

5.2 Short-Run Production (2 of 5)

The Marginal Product of Labor: $MP_L = \Delta q / \Delta L$

- Change in total output resulting from using an extra unit of labor, holding other factors (capital) constant.
 - Table 5.1 shows if the number of workers increases from 1 to 2, $\Delta L = 1$, output rises by $\Delta q = 13 = 18 - 5$, so the marginal product of labor is 13.
- When the change in labor is very small (infinitesimal), we use the **calculus definition of the marginal product of labor**.
 - Marginal Product of Labor is the partial derivative of the production function with respect to labor:
 - $MP_L = \partial q / \partial L = \partial f(L, K) / \partial L$

5.2 Short-Run Production (3 of 5)

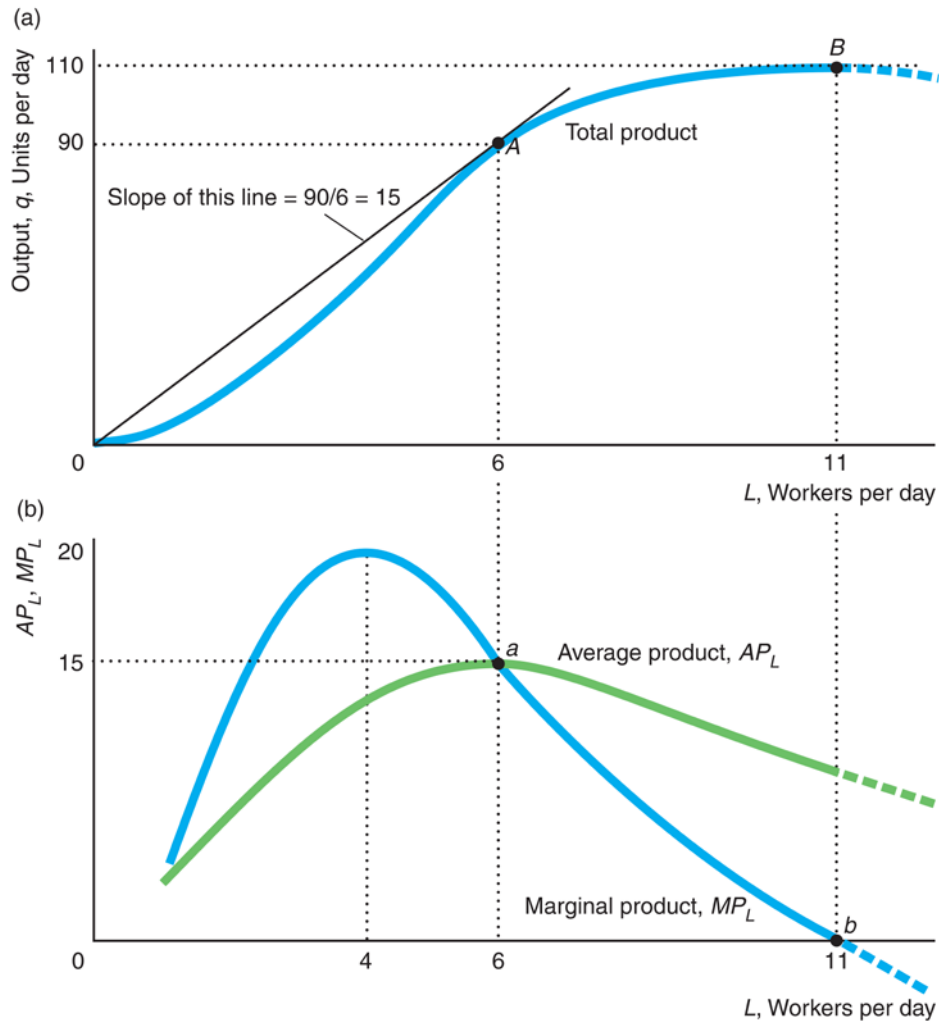
Graphing the Product Curves

- Figure 5.1 plots the data from Table 5.1. The figure shows how output (total product), the average product of labor, and the marginal product of labor vary with the number of workers.

The Effect of Extra Labor

- In panel a of Figure 5.1, output rises with labor until it reaches its maximum of 110 computers at 11 workers, point C.
- In panel b, the average product of labor first rises and then falls as labor increases. Also, the marginal product of labor first rises and then falls as labor increases.
- Average product may rise because of division of labor and specialization. Workers become more productive as we add more workers. Marginal product of labor goes up, and consequently average product goes up.
- Average product falls as the number of workers exceeds 6. Workers might have to wait to use equipment or get in each other's way because capital is constant. Because marginal product of labor goes down, average product goes down too.

Figure 5.1 Production Relationships with Variable Labor



5.2 Short-Run Production (4 of 5)

Relationships Among Product Curves

- The total, average and marginal curves are geometrically related.
- Average Product of Labor and Marginal Product of Labor
 - If the marginal product curve is above that average product curve, the average product must rise with extra labor.
 - If marginal product is below the average product then the average product must fall with extra labor.
 - Consequently, the average product curve reaches its peak where the marginal product and average product are equal (point a in panel b of Figure 5.1).
- Deriving AP_L and MP_L using the Total Production Function
 - The average product of labor for L workers equals the slope of a straight line from the origin to a point on the total product of labor curve for L workers in panel a of Figure 5.1.
 - The slope of the total product curve at a given point equals the marginal product of labor. That is, the marginal product of labor equals the slope of a straight line that is tangent to the total output curve at a given point.

5.2 Short-Run Production (5 of 5)

The Law of Diminishing Marginal Returns

- If a firm keeps increasing an input, holding all other inputs and technology constant, the corresponding increases in output will eventually become smaller (diminish).
 - This law comes from realizing most observed production functions have this property.
 - **Common Confusion:** “An input’s marginal product must eventually fall as a firm uses more of the input” is true only in the short run.
- The law of diminishing marginal returns determines the shape of the marginal product of labor curves:
 - if only one input is increased, **the marginal product of that input will diminish eventually.**

5.3 Long-Run Production (1 of 4)

- In the long run, labor L and capital K are variable.
- The firm can substitute one input for another while continuing to produce the same level of output, $\bar{q}$.

Isoquants: $q = f(L, K)$

- An isoquant shows the **efficient** combinations of labor and capital that can produce the same (**iso**) level of output (**quantity**).
 - In table 5.2, output q is produced with the combination of labor L and capital K .
 - In Figure 5.2, points a , b , c , and d show the same level of output, $q = 24$. This level of output is also highlighted in Table 5.2

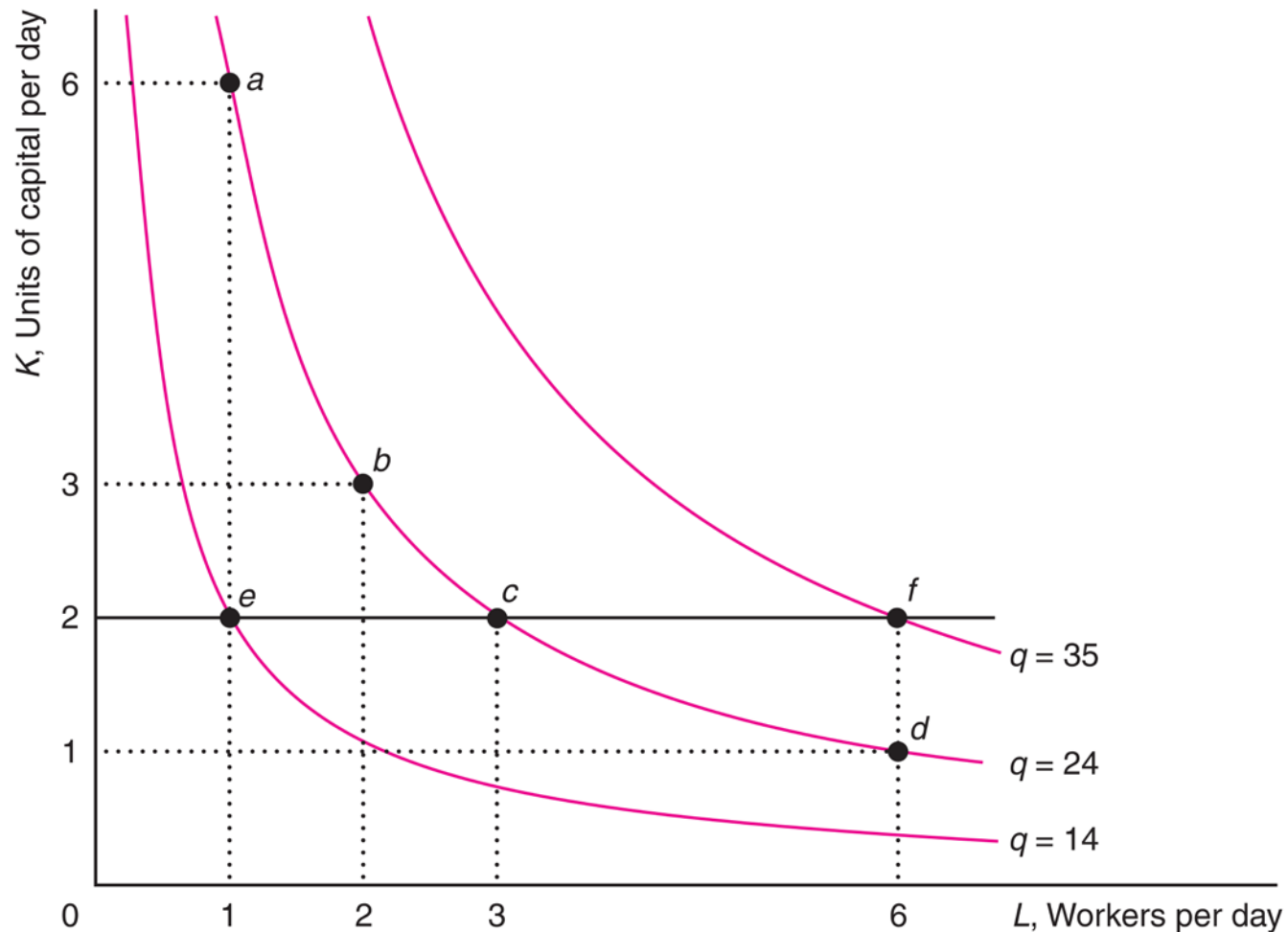
Properties of Isoquants

- The farther an isoquant is from the origin, the greater is the level of output.
- Isoquants do not cross.
- Isoquants slope downward.
 - All these properties can be verified in Figure 5.2.

Table 5.2 Output Produced with Two Variable Inputs

Capital, K	Labor, L					
	1	2	3	4	5	6
1	10	14	17	20	22	24
2	14	20	24	28	32	35
3	17	24	30	35	39	42
4	20	28	35	40	45	49
5	22	32	39	45	50	55
6	24	35	42	49	55	60

Figure 5.2 A Family of Isoquants

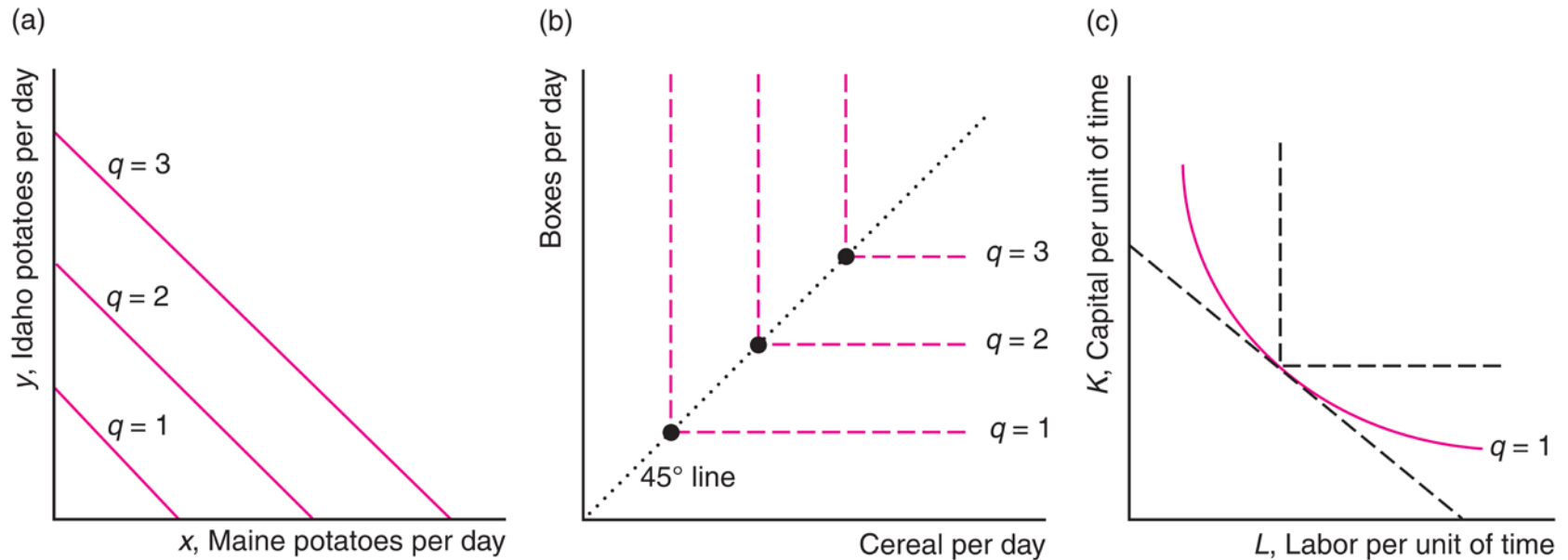


5.3 Long-Run Production (2 of 4)

Shapes of Isoquants

- If inputs are perfect substitutes, isoquants are straight lines.
 - In Figure 5.3, panel a, potato salad can be produced with potatoes from Idaho or Maine, both are perfect substitutes. Isoquants are straight lines with a slope of -1 .
- If inputs cannot be substituted at all, so inputs must be used in fixed proportions, isoquants are right angles.
 - In Figure 5.3, panel b, the production of 12-ounce boxes of cereal requires 1 box and 12-ounce of cereal, and this proportion is fixed. The efficient points of production are in the 45° line and the dashed lines are inefficient points.
- If inputs can be substituted imperfectly, isoquants are convex to the origin.
 - In Figure 5.3, panel c, the isoquant at level $q=1$ is convex, and the slope varies at each point of the isoquant.

Figure 5.3 Substitutability of Inputs



5.3 Long-Run Production (3 of 4)

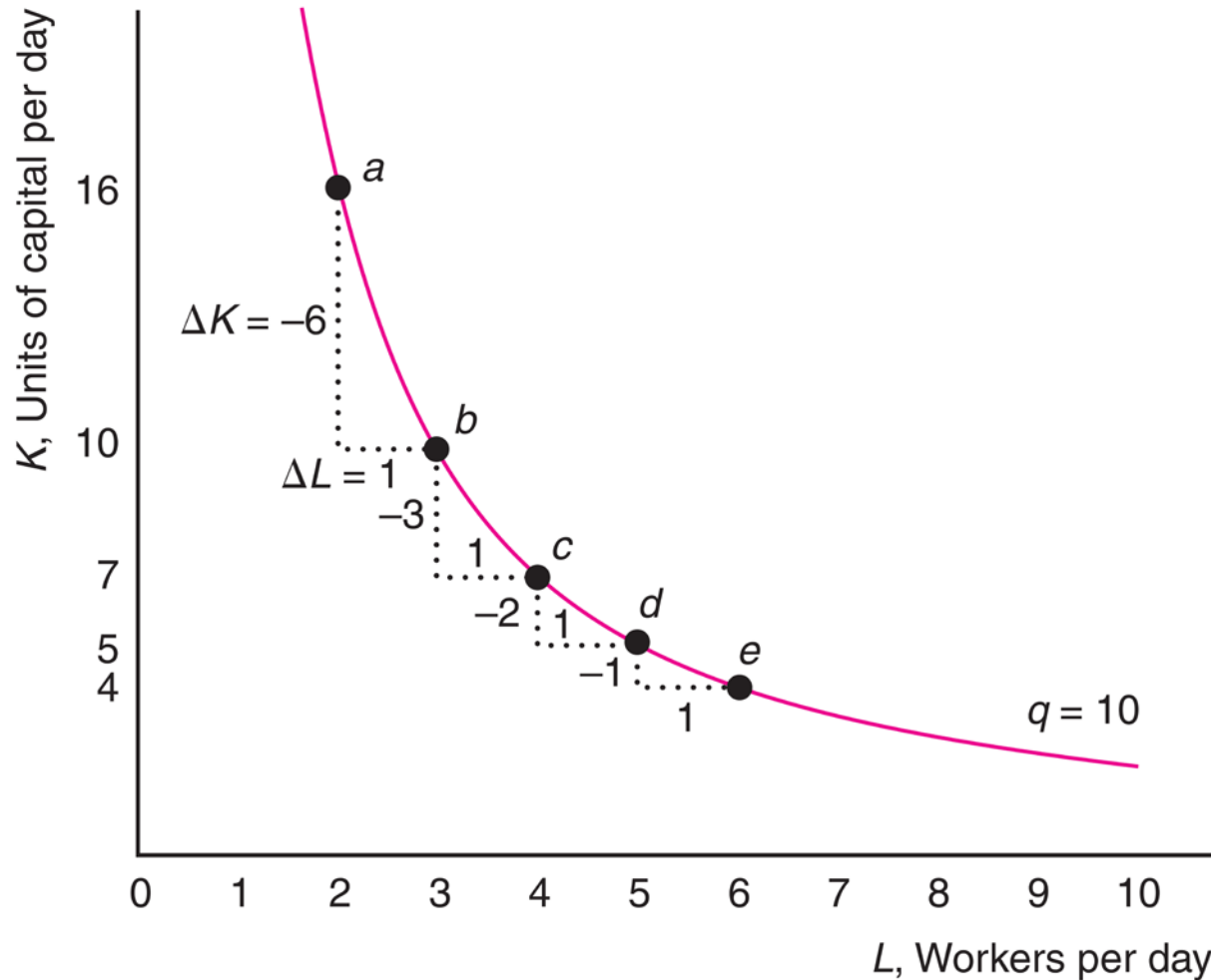
Substituting Inputs: $MRTS = \Delta K / \Delta L$

- The slope of an isoquant shows the ability of a firm to replace one input with another while holding output constant.
- This slope is the **marginal rate of technical substitution ($MRTS$)**: how many units of capital the firm can replace with an extra unit of labor while holding output constant.

Substitutability of Inputs Varies Along and Isoquant

- Diminishing $MRTS$ (absolute value): The more labor and less capital the firm has, the harder it is to replace remaining capital with labor and the flatter the isoquant becomes.
 - In Figure 5.4, the firm replaces 6 units of capital per 1 worker to remain on the same isoquant (a to b), so $MRTS = -6$. If the firm hires another worker (b to c), the firm replaces 3 units of capital, so $MRTS = -3$.

Figure 5.4 How the Marginal Rate of Technical Substitution Varies Along an Isoquant



5.3 Long-Run Production (4 of 4)

Substitutability of Inputs and Marginal Products

- The marginal rate of technical substitution is equal to the ratio of marginal products
 - $-MPL / MPK = \Delta K / \Delta L = MRTS$

Cobb-Douglas Production Functions: $q = AL^\alpha K^\beta$

- A, α , and β are all positive constants. This function is used to estimate many production processes, for instant the one in the mini-case: returns to scale for crocks.
- The marginal product of labor is $MP_L = \alpha q / L = \alpha AP_L$ and $\alpha = MP_L / AP_L$
- The marginal product of capital is $MP_K = \beta q / K = \beta AP_K$, and $\beta = MP_K / AP_K$
- $MRTS = -\alpha K / \beta L$

5.4 Returns to Scale (1 of 4)

Constant, Increasing, and Decreasing Returns to Scale



5.4 Returns to Scale (2 of 4)

- How much output changes if a firm increases **all** its inputs proportionately?
There are three possible answers:

Constant Returns to Scale (**CRS**): $f(2L, 2K) = 2f(L, K) = 2q$

- A technology exhibits constant returns to scale if doubling inputs exactly doubles the output. The firm builds an identical second plant and uses the same amount of labor and equipment as in the first plant.

Increasing Returns to Scale (**IRS**): $f(2L, 2K) > 2f(L, K) = 2q$

- A technology exhibits increasing returns to scale if doubling inputs more than doubles the output. Instead of building two small plants, the firm decides to build a single larger plant with greater specialization of labor and capital.

Decreasing Returns to Scale (**DRS**): $f(2L, 2K) < 2f(L, K) = 2q$

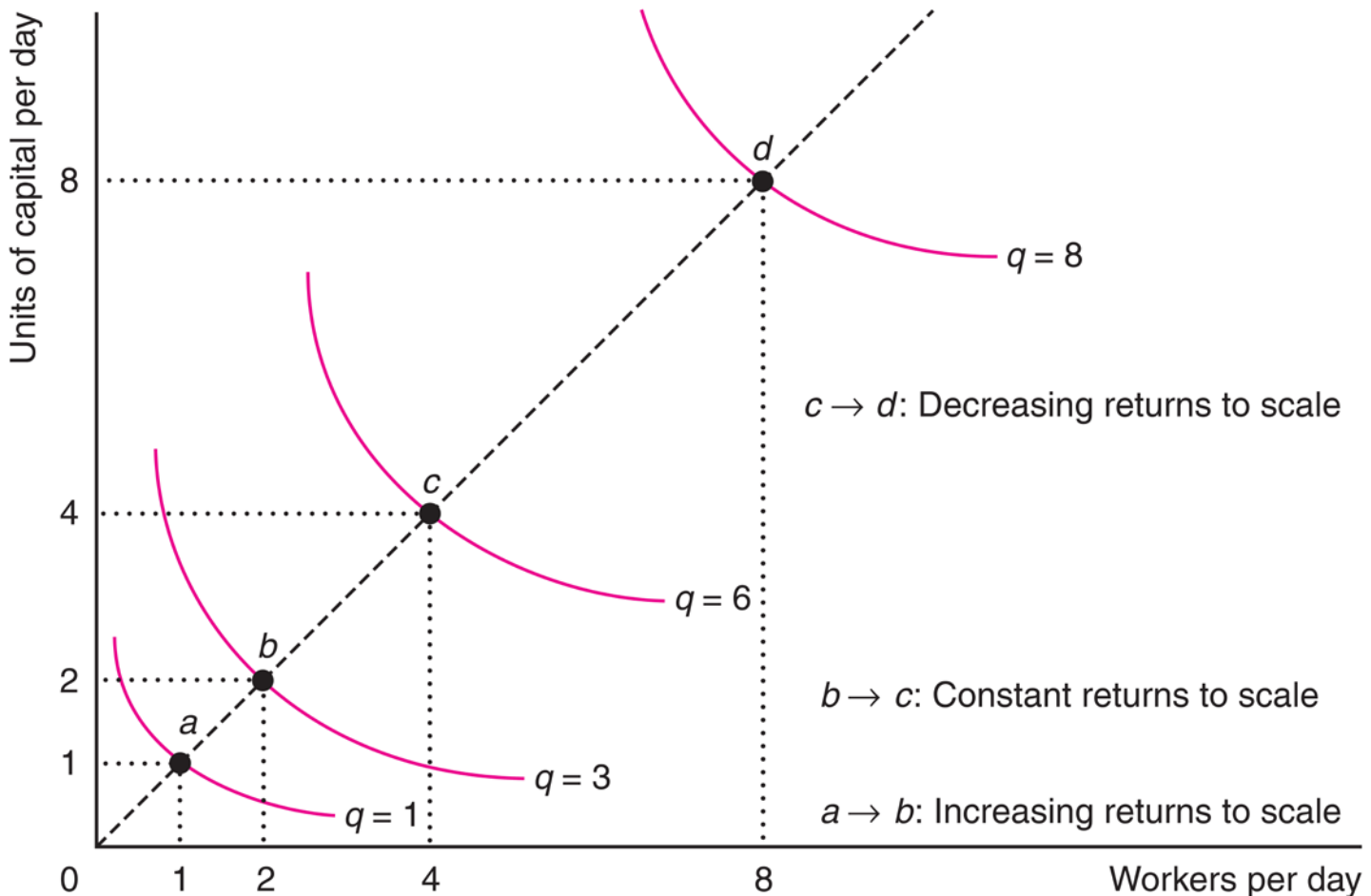
- A technology exhibits decreasing returns to scale if doubling inputs less than doubles output. An owner may be able to manage one plant well but may have trouble organizing, coordinating, and integrating activities in two plants.

5.4 Returns to Scale (3 of 4)

Varying Returns to Scale

- Many production functions have increasing returns to scale for small amounts of output, constant returns for moderate amounts of output, and decreasing returns for large amounts of output.
- Graphical Analysis
 - Figure 5.5, *a* to *b*: When a firm is small, increasing labor and capital allows for gains from cooperation between workers and greater specialization of workers and equipment, so there are increasing returns to scale
 - Figure 5.5, *b* to *c*: As the firm grows, returns to scale are eventually exhausted. There are no more returns to specialization, so the production process has constant returns to scale.
 - Figure 5.5, *c* to *d*: If the firm continues to grow, the owner starts having difficulty managing everyone, so the firm suffers from decreasing returns to scale.

Figure 5.5 Varying Scale Economies



5.4 Returns to Scale (4 of 4)

Managerial Implication: Small Is Beautiful

- Over the years, the typical factory has grown in size to take advantage of increasing returns to scale. However, 3D printing may reverse this trend by making input requirements per unit to manufacture one item as low as when making thousands.
- 3D printing is now used in manufacturing final products, particularly in industries that need small numbers of customized parts.
 - Nike is using it to produce the Zoom Superfly Skyknit running shoe. Biomedical and aerospace companies like Boeing and Airbus use it for just-in-time manufacturing. Airbus introduced the world's first entirely 3D-printed aircraft, a drone, in 2016.
- Managers should experiment with 3D. They can produce small initial runs to determine the size of the market and consumers' acceptance of the product. Based on information from early adopters, managers can determine if the market warrants further production and can quickly modify designs to meet end-users' desires.

5.5 Innovation (1 of 2)

- Innovation, a new idea, device or method, affects markets in many ways.
- We, consumers, are familiar with product innovations. But in the context of production, we focus on **process and organizational innovations**.

Process Innovation (new method of production)

- A **process innovation** changes the production function: more output to be produced with the same level of inputs (technological progress).
 - Technological progress is **neutral** if more output is produced using the same ratio of inputs.
 - Technological progress is **nonneutral** if it is **capital or labor saving**.

Organizational Innovation (new way of organizing)

- **Organizational innovations** may also alter the production function and increase the amount of output produced by a given amount of inputs.
 - In the early 1900s, Henry Ford revolutionized mass car production through interchangeable parts and the assembly line.

5.5 Innovation (2 of 2)

Managerial Implication:

Technical Progress and Competitive Advantage

- In some industries, an important part of being a good manager involves adopting new technologies and looking for better ways to organize the firm.
- A firm that achieves a successful process or organizational innovation can produce more output with the same input levels than its rivals, which gives it a competitive advantage.

Managerial Problem Solution

Labor Productivity During Recessions

- How much will the output produced per worker rise or fall with each additional layoff?

Solution

- Layoffs have the positive effect of freeing up machines to be used by remaining workers. However, if layoffs force the remaining workers to perform a wide variety of tasks, the firm will lose the benefits from specialization.
- Holding capital constant, a change in the number of workers affects a firm's average product of labor. Labor productivity could rise or fall.
- For some production functions layoffs always raise labor productivity because the AP_L curve is everywhere downward sloping, for instance the Cobb-Douglass production function.

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