Bonus Web Chapter

11

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IN THIS CHAPTER YOU WILL LEARN:

1 The differences between invention, innovation, and technological diffusion.

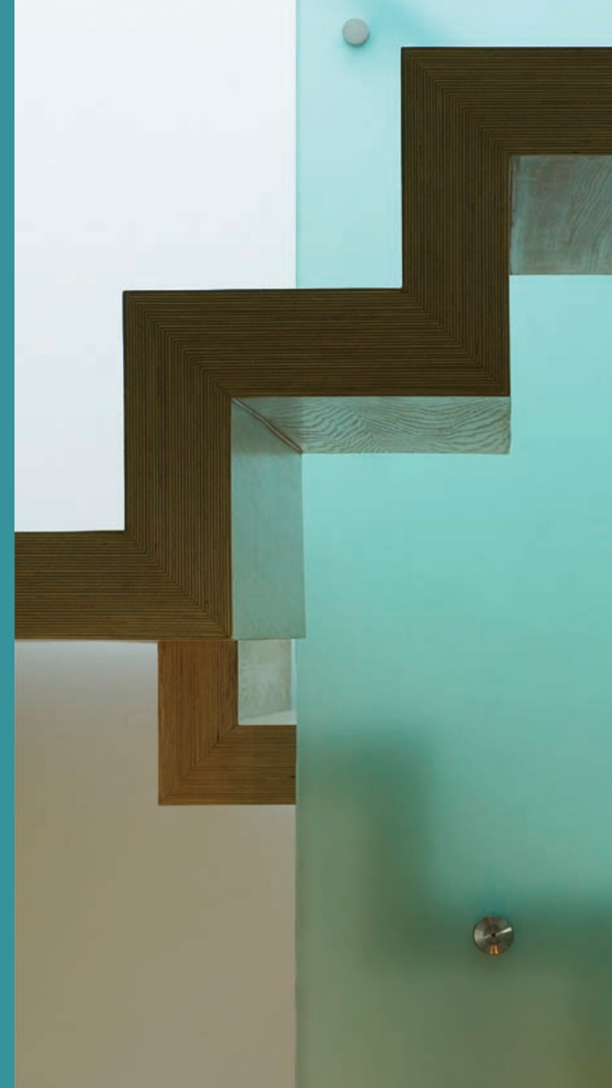
2 How entrepreneurs and other innovators further technological advance.

3 How a firm determines its optimal amount of research and development (R&D).

4 Why firms can benefit from their innovation even though rivals have an incentive to imitate it.

5 About the role of market structure in promoting technological advance.

6 How technological advance enhances productive efficiency and allocative efficiency.



Technology, R&D, and Efficiency

- "Just do it!" In 1968 two entrepreneurs from Oregon developed a lightweight sport shoe and formed a new company called Nike, incorporating a "swoosh" logo (designed by a graduate student for $35). Today, Nike sells $16 billion worth of goods annually.
- "Leap Ahead." In 1967 neither Intel nor its product existed. Today it is the world's largest producer of microprocessors for personal computers, with about $35 billion of annual sales.
- "Save money, live better." Expanding from a single store in 1962 to about 7000 stores worldwide today, Wal-Mart's annual revenue ($349 billion) exceeds that of General Motors or IBM.

Nike, Intel, and Wal-Mart owe much of their success to **technological advance,** broadly defined as new and better goods and services or new and better ways of producing or distributing them. Nike and

Intel pioneered innovative new products, and Wal-Mart developed creative ways to manage inventories and distribute goods.

Multiply these examples—perhaps on a smaller scale—by thousands in the economy! The pursuit of technological advance is a major competitive activity among firms. In this chapter, we examine some of the microeconomics of that activity.

Invention, Innovation, and Diffusion

For economists, technological advance occurs over a theoretical time period called the *very long run*, which can be as short as a few months or as long as many years. Recall that in our four market models (pure competition, monopolistic competition, oligopoly, and pure monopoly), the short run is a period in which technology and plant and equipment are fixed. In the long run, technology is constant but firms can change their plant sizes and are free to enter or exit industries. In contrast, the **very long run** is a period in which technology can change and in which firms can develop and offer entirely new products.

In Chapter 1 we saw that technological advance shifts an economy's production possibilities curve outward, enabling the economy to obtain more goods and services. Technological advance is a three-step process of invention, innovation, and diffusion.

Invention

The basis of technological advance is **invention:** the discovery of a product or process through the use of imagination, ingenious thinking, and experimentation and the first proof that it will work. Invention is a process, and the result of the process is also called *an* invention. The prototypes (basic working models) of the telephone, the automobile, and the microchip are inventions. Invention usually is based on scientific knowledge and is the product of individuals, working either on their own or as members of corporate R&D staffs. Later on you will see how governments encourage invention by providing the inventor with a **patent,** an exclusive right to sell any new and useful process, machine, or product for a set period of time. In 2006 the top 10 firms that secured the most U.S. patents were IBM (3621), Samsung (2451), Canon (2366), Matsushita (2229), Hewlet-Packard (2099), Intel (1959), Sony (1771), Hitachi (1732), Toshiba (1672), and Micron Technology (1610). Numbers like these, of course, do not reveal the quality of the patents received; some patents are much more significant than other patents. Patents have a worldwide duration of 20 years from the time of application for the patent.

Innovation

Innovation draws directly on invention. While invention is the "discovery and first proof of workability," **innovation** is the first successful commercial introduction of a new product, the first use of a new method, or the creation of a new form of business enterprise. Innovation is of two types: **product innovation,** which refers to new and improved products or services; and **process innovation,** which refers to new and improved methods of production or distribution.

Unlike inventions, innovations cannot be patented. Nevertheless, innovation is a major factor in competition, since it sometimes enables a firm to "leapfrog" competitors by rendering their products or processes obsolete. For example, personal computers coupled with software for word processing pushed some major typewriter manufacturers into obscurity. More recently, innovations in hardware retailing (large warehouse stores such as Home Depot) have threatened the existence of smaller, more traditional hardware stores.

But innovation need not weaken or destroy existing firms. Aware that new products and processes may threaten their survival, existing firms have a powerful incentive to engage continuously in R&D of their own. Innovative products and processes often enable such firms to maintain or increase their profits. The introduction of disposable contact lenses by Johnson & Johnson, scientific calculators by Hewlett-Packard, and iPhones by Apple are good examples. Thus, innovation can either diminish or strengthen market power.

Diffusion

Diffusion is the spread of an innovation to other products or processes through imitation or copying. To take advantage of new profit opportunities or to slow the erosion of profit, both new and existing firms emulate the successful innovations of others. Alamo greatly increased its auto rentals by offering customers unlimited mileage, and Hertz, Avis, Budget, and others eventually followed. DaimlerChrysler profitably introduced a luxury version of its Jeep Grand Cherokee; other manufacturers, including Acura, Mercedes, and Lexus, countered with luxury sport-utility vehicles of their own.

In 1996 Palm introduced its Palm Pilot, a palm-size personal computer. Microsoft, Handspring, OmniSky, and other firms soon brought out similar products.

Other recent examples: Early successful cholesterol-reducing drugs (statins) such as Bristol-Myers Squibb's Provochol were soon followed by chemically distinct but similar statins such as Merck's Zocor and Pfizer's Lipitor. Early video game consoles such as those by Atari eventually gave rise to more popular consoles by Nintendo (Wii), Sony (PlayStation), and Microsoft (Xbox). MySpace, Facebook, and LinkedIn mimicked the social networking innovation pioneered by Classmates.com.

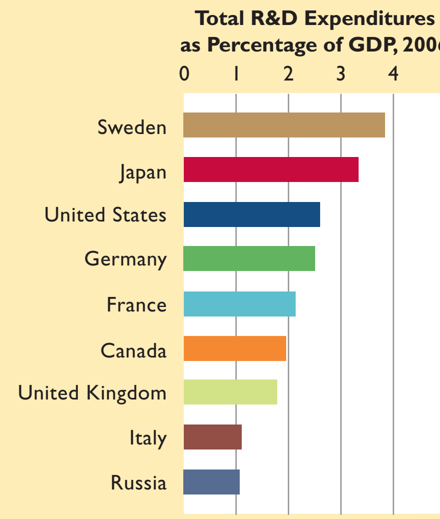
In each of these cases, other firms incorporated the new innovation into their own business and products through imitation, modification, and extension. The original innovation thus became commonplace and mainly of historical interest.

Although not as dramatic as invention and innovation, diffusion is a critical element of technological change.

GLOBAL PERSPECTIVE 11W.1

Total R&D Expenditures as a Percentage of GDP, Selected Nations

Relative R&D spending varies among leading industrial nations. From a microeconomic perspective, R&D helps promote economic efficiency; from a macroeconomic perspective, R&D helps promote economic growth.



Source: National Science Foundation, **www.nsf.gov,** and Organization for Economic Cooperation and Development, **www.oecd.org.**

R&D Expenditures

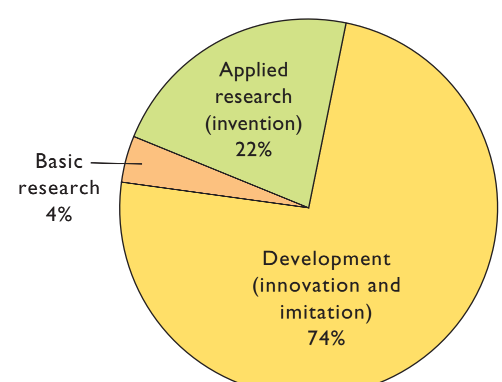
As related to *businesses*, the term "research and development" is used loosely to include direct efforts toward invention, innovation, and diffusion. However, *government* also engages in R&D, particularly R&D having to do with national defense. In 2006 *total* U.S. R&D expenditures (business *plus* government) were $343 billion. Relative to GDP that amount was about 2.6 percent, which is a reasonable measure of the emphasis the U.S. economy puts on technological advance. As shown in Global Perspective 11W.1, this is a high percentage of GDP compared to several other nations.

American businesses spent $242 billion on R&D in 2006. Figure 11W.1 shows how these R&D expenditures were allocated. Observe that U.S. firms collectively channeled 74 percent of their R&D expenditures to "development" (innovation and imitation, the route to diffusion). They spent another 22 percent on applied research, or on pursuing invention. For reasons we will mention later, only 4 percent of business R&D expenditures went for basic research, the search for general scientific principles. Of course, industries, and firms within industries, vary greatly in the amount of emphasis they place on these three processes.

Modern View of Technological Advance

For decades most economists regarded technological advance as being external to the economy—a random outside force to which the economy adjusted. From time to time fortuitous advances in scientific and technological knowledge occurred, paving the way for major new products (automobiles, airplanes) and new production processes (assembly lines). Firms and industries, each at its own pace, then incorporated the new technology into their products

FIGURE 11W.1 The composition of business R&D outlays in the United States, 2006. Firms channel the bulk of their R&D spending to innovation and imitation, because both have direct commercial value; less to applied research, that is, invention; and a relatively small amount to basic scientific research.



Source: National Science Foundation, **www.nsf.gov.**

or processes to enhance or maintain their profit. After making the appropriate adjustments, they settled back into new long-run equilibrium positions. Although technological advance has been vitally important to the economy, economists believed it was rooted in the independent advance of science, which is largely external to the market system.

Most contemporary economists have a different view. They see capitalism itself as the driving force of technological advance. Invention, innovation, and diffusion occur in response to incentives within the economy, meaning that technological advance is *internal* to capitalism. Specifically, technological advance arises from intense rivalry among individuals and firms that motivates them to seek and exploit new profit opportunities or to expand existing opportunities. That rivalry occurs both among existing firms and between existing firms and new firms. Moreover, many advances in "pure" scientific knowledge are motivated, at least in part, by the prospect of commercial applicability and eventual profit. In the modern view, entrepreneurs and other innovators are at the heart of technological advance.

Role of Entrepreneurs and Other Innovators

It will be helpful to distinguish between "entrepreneurs" and "other innovators":

- ***Entrepreneurs*** Recall that the entrepreneur is an initiator, innovator, and risk bearer—the resource that combines land, labor, and capital resources in new and unique ways to produce new goods and services. In the past a single individual, for example, Andrew Carnegie in steel, Henry Ford in automobiles, or Levi Strauss in blue jeans, carried out the entrepreneurial role. Such advances as air conditioning, the ballpoint pen, cellophane, the jet engine, insulin, xerography, and the helicopter all have an individualistic heritage. But in today's more technologically complex economy, entrepreneurship is just as likely to be carried out by entrepreneurial teams. Such teams may include only two or three people working "as their own bosses" on some new product idea or it may consist of larger groups of entrepreneurs who have pooled their financial resources.
- ***Other innovators*** This designation includes other key people involved in the pursuit of innovation who do not bear personal financial risk. Among them are key executives, scientists, and other salaried employees engaged in commercial R&D activities. (They are sometimes referred to as *intrapreneurs* since they provide the spirit of entrepreneurship within existing firms.)

Forming Start-Ups

Entrepreneurs often form small new companies called **start-ups** that focus on creating and introducing a new product or employing a new production or distribution technique. Two people, working out of their garages, formed such a start-up in the mid-1970s. Since neither of their employers—Hewlett-Packard and Atari, the developer of Pong (the first video game)—was interested in their prototype personal computer, they founded their own computer company: Apple. Other examples of successful start-ups are Amgen, a biotechnology firm specializing in new medical treatments; Starbucks, a seller of gourmet coffee; Amazon, an Internet retailer; and Google, an Internet search provider.

Innovating within Existing Firms

Innovators are also at work within existing corporations, large and small. Such innovators are salaried workers, although many firms have pay systems that provide them with substantial bonuses or profit shares. Examples of firms known for their skillful internal innovators are 3M Corporation, the U.S. developer of Scotch tape, Post-it Note Pads, and Thinsulate insulation; and General Electric, the developer of innovative major kitchen appliances, medical imaging machines, and jet aircraft engines. R&D work in major corporations has produced significant technological improvements in such products as television sets, telephones, home appliances, automobiles, automobile tires, and sporting equipment.

Some large firms, aware that excessive bureaucracy can stifle creative thinking and technological advance, have separated part of their R&D and manufacturing divisions to form new, more flexible, innovative firms. Three significant examples of such "spin-off firms" are Lucent Technologies, a telephone equipment and R&D firm created by AT&T; Imation, a high-technology firm spun off by the 3M Corporation; and Yum Brands, which operates restaurant chains Taco Bell, KFC, and Pizza Hut, spun off from Pepsi.

Anticipating the Future

About a half-century ago a writer for *Popular Mechanics* magazine boldly predicted, "Computers in the future may weigh no more than 1.5 tons." Today's notebook computers weigh less than 3 pounds.

Anticipating the future is difficult, but that is what innovators try to do. Those with strong anticipatory ability and determination have a knack for introducing new and improved products or services at just the right time.

The rewards for success are both monetary and nonmonetary. Product innovation and development are creative endeavors, with such intangible rewards as personal satisfaction. Also, many people simply enjoy participating in the competitive "contest." Of course, the "winners" can reap huge monetary rewards in the form of economic profits, stock appreciation, or large bonuses. Extreme examples are Bill Gates and Paul Allen, who founded Microsoft in 1975, and had a net worth in 2007 of $56 billion and $18 billion, respectively, mainly in the form of Microsoft stock.

Past successes often give entrepreneurs and innovative firms access to resources for further innovations that anticipate consumer wants. Although they may not succeed a second time, the market tends to entrust the production of goods and services to businesses that have consistently succeeded in filling consumer wants. And the market does not care whether these "winning" entrepreneurs and innovative firms are American, Brazilian, Japanese, German, or Swiss. Entrepreneurship and innovation are global in scope.

Exploiting University and Government Scientific Research

In Figure 11W.1 we saw that only 4 percent of business R&D spending in the United States goes to basic scientific research. The reason the percentage is so small is that scientific principles, as such, cannot be patented, nor do they usually have immediate commercial uses. Yet new scientific knowledge is highly important to technological advance. For that reason, entrepreneurs study the scientific output of university and government laboratories to identify discoveries with commercial applicability.

Government and university labs have been the scene of many technological breakthroughs, including hybrid seed corn, nuclear energy, satellite communications, the computer "mouse," genetic engineering, and the Internet. Entire high-tech industries such as computers and biotechnology have their roots in major research universities and government laboratories. And nations with strong scientific communities tend to have the most technologically progressive firms and industries.

Also, firms increasingly help fund university research that relates to their products. Business funding of R&D at universities has grown rapidly, rising to more than $2.4 billion in 2006. Today, the separation between university scientists and innovators is narrowing; scientists and universities increasingly realize that their work may have commercial value and are teaming up with innovators to share in the potential profit.

A few firms, of course, find it profitable to conduct basic scientific research on their own. New scientific knowledge can give them a head start in creating an invention or a new product. This is particularly true in the pharmaceutical industry, where it is not uncommon for firms to parlay new scientific knowledge generated in their corporate labs into new, patentable drugs.

QUICK REVIEW 11W.1

- Broadly defined, technological advance means new or improved products and services and new or improved production and distribution processes.
- Invention is the *discovery* of a new product or method; innovation is the *successful commercial application* of some invention; and diffusion is the *widespread adoption* of the innovation.
- Many economists view technological advance as mainly a response to profit opportunities arising within a capitalist economy.
- Technological advance is fostered by entrepreneurs and other innovators and is supported by the scientific research of universities and government-sponsored laboratories.

A Firm's Optimal Amount of R&D

How does a firm decide on its optimal amount of research and development? That amount depends on the firm's perception of the marginal benefit and marginal cost of R&D activity. The decision rule here flows from basic economics: To earn the greatest profit, expand a particular activity until its marginal benefit (MB) equals its marginal cost (MC). A firm that sees the marginal benefit of a particular R&D activity, say, innovation, as exceeding the marginal cost should expand that activity. In contrast, an activity whose marginal benefit promises to be less than its marginal cost should be cut back. But the R&D spending decision is complex since it involves a present sacrifice for a future expected gain. While the cost of R&D is immediate, the expected benefits occur at some future time and are highly uncertain. So estimating those benefits is often more art than science. Nevertheless, the MB = MC way of thinking remains relevant for analyzing R&D decisions.

Interest-Rate Cost of Funds

Firms have several ways of obtaining the funds they need to finance R&D activities:

- ***Bank loans*** Some firms are able to obtain a loan from a bank or other financial institution. Then the cost of using the funds is the interest paid to the lender. The marginal cost is the cost per extra dollar borrowed, which is simply the market interest rate for borrowed funds.
- ***Bonds*** Established, profitable firms may be able to borrow funds for R&D by issuing bonds and selling them in the bond market. In this case, the cost is the

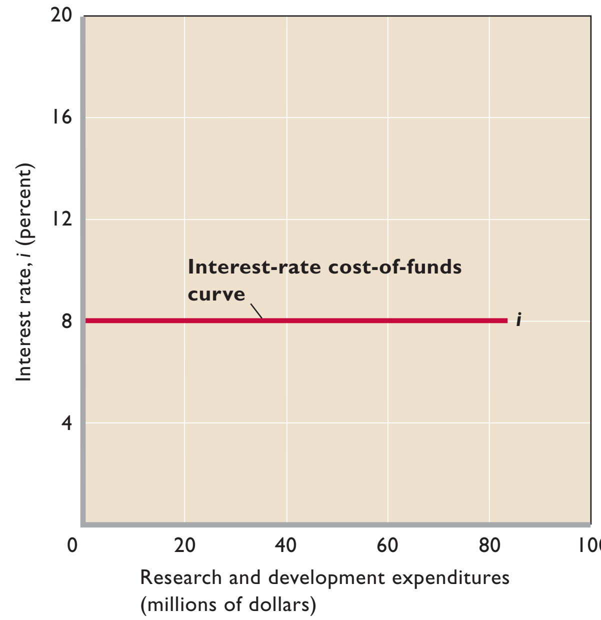
interest paid to the lenders—the bondholders. Again the marginal cost of using the funds is the interest rate. (We discussed corporate bonds in Chapter 4.)

- ***Retained earnings*** A large, well-established firm may be able to draw on its own corporate savings to finance R&D. Typically, such a firm retains part of its profit rather than paying it all out as dividends to corporate owners. Some of the undistributed corporate profit, called *retained earnings*, can be used to finance R&D activity. The marginal cost of using retained earnings for R&D is an opportunity cost—the rate of interest that those funds could have earned as deposits in a financial institution.
- ***Venture capital*** A smaller start-up firm might be able to attract venture capital to finance its R&D projects. Venture capital is financial capital, or simply money, not real capital. **Venture capital** consists of that part of household saving used to finance high-risk business ventures in exchange for shares of the profit if the ventures succeed. The marginal cost of venture capital is the share of expected profit that the firm will have to pay to those who provided the money. This can be stated as a percentage of the venture capital, so it is essentially an interest rate.
- ***Personal savings*** Finally, individual entrepreneurs might draw on their own savings to finance the R&D for a new venture. The marginal cost of the financing is again the forgone interest rate.

Thus, whatever the source of the R&D funds, we can state the marginal cost of these funds as an interest rate i. For simplicity, let's assume that this interest rate is the same no matter how much financing is required. Further, we assume that a certain firm called MedTech must pay an interest rate of 8 percent for the least expensive funding available to it. Then a graph of the marginal cost of each funding amount for this firm is a horizontal line at the 8 percent interest rate, as shown in Figure 11W.2. Such a graph is called an **interest-rate cost-of-funds curve.** This one tells us that MedTech can borrow $10, $10,000, $10,000,000, or more at the 8 percent interest rate. The table accompanying the graph contains the data used to construct the graph and tells us much the same thing.

With these data in hand, MedTech wants to determine how much R&D to finance in the coming year.

FIGURE 11W.2 The interest-rate cost-of-funds schedule and curve. As it relates to R&D, a firm's interest-rate cost-of-funds schedule (the table) and curve (the graph) show the interest rate the firm must pay to obtain any particular amount of funds to finance R&D. Curve *i* indicates the firm can finance as little or as much R&D as it wants at a constant 8 percent rate of interest.

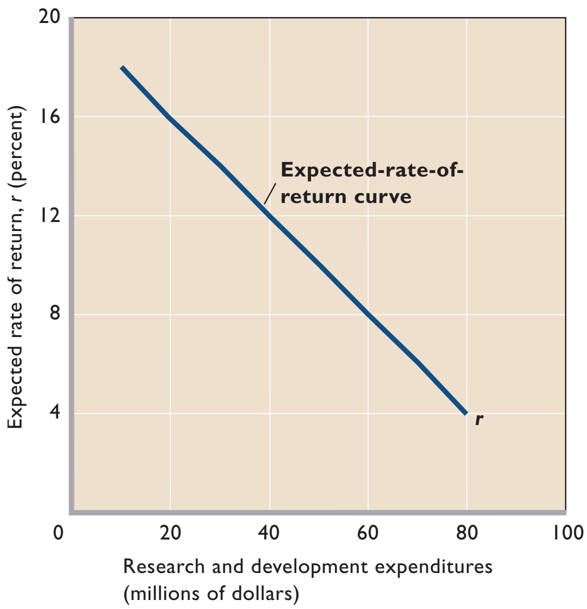


R&D, Millions	Interest-Rate Cost of Funds, %
$10	8
20	8
30	8
40	8
50	8
60	8
70	8
80	8

Expected Rate of Return

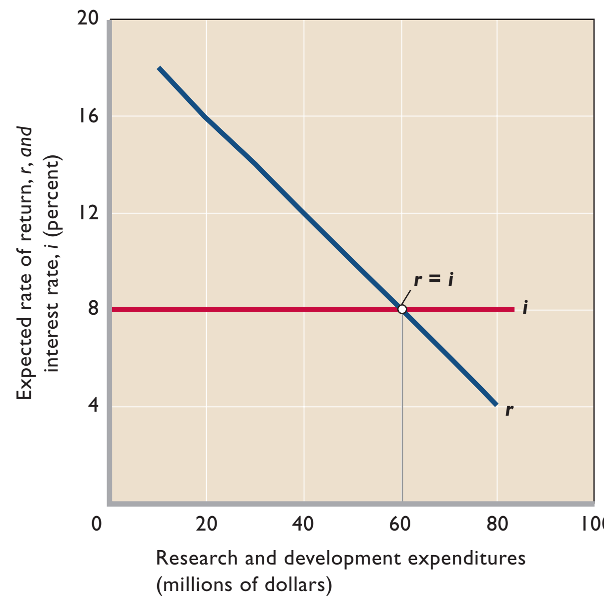
A firm's marginal benefit from R&D is its expected profit (or return) from the last (marginal) dollar spent on R&D. That is, the R&D is expected to result in a new product or production method that will increase revenue, reduce production costs, or both (in ways we will soon explain). This return is expected, not certain—there is risk in R&D decisions. Let's suppose that after considering such risks, MedTech anticipates that an R&D expenditure of $1 million will result in a new product that will yield a one-time added profit of $1.2 million a year later. The expected rate of return r on the $1 million R&D expenditure (after the $1 million has been repaid) is 20 percent (= $200,000/$1,000,000). This is the marginal benefit of the first $1 million of R&D. (Stretching the return over several years complicates the computation of r, but it does not alter the basic analysis. We discuss this "present-value complication" in Chapter 15.)

FIGURE 11W.3 The expected-rate-of-return schedule and curve. As they relate to R&D, a firm's expected-rate-of-return schedule (the table) and curve (the graph) show the firm's expected gain in profit, as a percentage of R&D spending, for each level of R&D spending. Curve *r* slopes downward because the firm assesses its potential R&D projects in descending order of expected rates of return.



R&D, Millions	Expected Rate of Return, %
$10	18
20	16
30	14
40	12
50	10
60	8
70	6
80	4

FIGURE 11W.4 A firm's optimal level of R&D expenditures. The firm's optimal level of R&D expenditures ($60 million) occurs where its expected rate of return equals the interest-rate cost of funds, as shown in both the table and the graph. At $60 million of R&D spending, the firm has taken advantage of all R&D opportunities for which the expected rate of return, *r*, exceeds or equals the 8 percent interest cost of borrowing, *i*.



Expected Rate of Return, %	R&D, Millions	Interest-Rate Cost of Funds, %
18	$10	8
16	20	8
14	30	8
12	40	8
10	50	8
8	***60***	***8***
6	70	8
4	80	8

MedTech can use this same method to estimate the expected rates of return for R&D expenditures of $2 million, $3 million, $4 million, and so on. Suppose those marginal rates of return are the ones indicated in the table in Figure 11W.3, where they are also graphed as the **expected-rate-of-return curve.** This curve shows the expected rate of return, which is the marginal benefit of each dollar of expenditure on R&D. The curve slopes downward because of diminishing returns to R&D expenditures. A firm will direct its initial R&D expenditures to the highest expected-rate-of-return activities and then use additional funding for activities with successively lower expected rates of return. That is, the firm will experience lower and lower expected rates of return as it expands its R&D spending.

Optimal R&D Expenditures

Figure 11W.4 combines the interest-rate cost-of-funds curve (Figure 11W.2) and the expected-rate-of-return curve (Figure 11W.3). The curves intersect at MedTech's **optimal amount of R&D,** which is $60 million. This amount can also be determined from the table as the amount of funding for which the expected rate of return and the interest cost of borrowing are equal (here, 8 percent).

Both the curve and the table in Figure 11W.4 tell us that at $60 million of R&D expenditures, the marginal benefit and marginal cost of the last dollar spent on R&D are equal. MedTech should undertake all R&D expenditures up to $60 million since those outlays yield a higher marginal benefit or expected rate of return, *r*, than the 8 percent

WORKED PROBLEMS

W 11W.1

Optimal R&D expenditures

marginal cost or interest-rate cost of borrowing, i. But it should not undertake R&D expenditures beyond $60 million; for these outlays, r (marginal benefit) is less than i (marginal cost). Only at $60 million do we have $r = i$, telling us that MedTech will spend $60 million on R&D.

Our analysis reinforces three important points:

- ***Optimal versus affordable R&D*** From earlier discussions we know there can be too much, as well as too little, of a "good thing." So it is with R&D and technological advance. Figure 11W.4 shows that R&D expenditures make sense to a firm only as long as the expected return from the outlay equals or exceeds the cost of obtaining the funds needed to finance it. Many R&D expenditures may be affordable but not worthwhile because their marginal benefit is likely to be less than their marginal cost.
- ***Expected, not guaranteed, returns*** The outcomes from R&D are expected, not guaranteed. With 20-20 hindsight, a firm can always look back and decide whether a particular expenditure for R&D was worthwhile. But that assessment is irrelevant to the original decision. At the time of the decision, the expenditure was thought to be worthwhile on the basis of existing information and expectations. Some R&D decisions may be more like an informed gamble than the typical business decision. Invention and innovation, in particular, carry with them a great deal of risk. For every successful outcome, there are scores of costly disappointments.
- ***Adjustments*** Firms adjust their R&D expenditures when expected rates of return on various projects change (when curves such as r in Figure 11W.4 shift). The U.S. war on terrorism, for example, increased the expected rate of return on R&D for improved security devices used at airports, train stations, harbors, and other public places. It also increased the expected return on new methods of detecting and responding to potential bioterrorism. The revised realities prompted many firms to increase their R&D expenditures for these purposes. **(Key Questions 4 and 5)**

Increased Profit via Innovation

In discussing how a firm determines its optimal amount of R&D spending, we sidestepped the question of how technological change can increase a firm's profit. Although the answer may seem obvious—by increasing revenue or reducing production costs—insights can be gained by exploring these two potential outcomes in some detail.

Increased Revenue via Product Innovation

Firms here and abroad have profitably introduced hundreds of new products in the past two or three decades. Examples include roller blades, microwave popcorn, cordless drills, digital cameras, camcorders, and high-definition TVs. Other new products are snowboards, cellular phones, MP3 players, and automobile air bags. All these items reflect technological advance in the form of product innovation.

How do such new products gain consumer acceptance? As you know from Chapter 7, to maximize their satisfaction, consumers purchase products that have the highest marginal utility per dollar. They determine which products to buy in view of their limited money incomes by comparing the ratios of MU/price for the various goods. They first select the unit of the good with the highest MU/price ratio, then the one with the next highest, and so on, until their incomes are used up.

The first five columns of Table 11W.1 repeat some of the information in Table 7.1. Before the introduction of new product C, the consumer maximized the total utility she could get from $10 of income by buying 2 units of A at $1 per unit and 4 units of B at $2 per unit. The total $10 budget was thus expended, with $2 spent on A and $8 on B. As shown in columns 2b and 3b, the marginal utility per dollar spent on the last unit of each product was 8 (= 8/$1 = 16/$2). The total utility, derived from columns 2a and 3a, was 96 utils (= 10 + 8 from the first 2 units of A plus 24 + 20 + 18 + 16 from the first 4 units of B). (If you are uncertain about this outcome, please review the discussion of Table 7.1.)

Now suppose an innovative firm offers new product C (columns 4a and 4b in Table 11W.1), priced at $4 per unit. Note that the first unit of C has a higher marginal utility per dollar (13) than any unit of A and B and that the second unit of C and the first unit of B have equal MU/price ratios of 12. To maximize satisfaction, the consumer now buys 2 units of C at $4 per unit, 1 unit of B at $2 per unit, and zero units of A. Our consumer has spent the entire $10 of income ($8 on C and $2 on B), and the MU/price ratios of the last units of B and C are equal at 12. But as determined via columns 3a and 4a, the consumer's total utility is now 124 utils (= 24 from the first unit of B plus 52 + 48 from the first 2 units of C).

Total utility has increased by 28 utils (= 124 utils − 96 utils), and that is why product C was purchased. Consumers will buy a new product only if it increases the total utility they obtain from their limited incomes.

TABLE 11W.1 Utility Maximization with the Introduction of a New Product (Income = $10)*

(1) Unit of Product	(2) Product A: Price = $1 (a) Marginal Utility, Utils	(b) Marginal Utility per Dollar (MU/Price)	(3) Product B: Price = $2 (a) Marginal Utility, Utils	(b) Marginal Utility per Dollar (MU/Price)	(4) New Product C: Price = $4 (a) Marginal Utility, Utils	(b) Marginal Utility per Dollar (MU/Price)
First	10	10	24	***12***	52	13
Second	8	***8***	20	10	48	***12***
Third	7	7	18	9	44	11
Fourth	6	6	16	***8***	36	9
Fifth	5	5	12	6	32	8

*It is assumed in this table that the amount of marginal utility received from additional units of each of the three products is independent of the quantity purchased of the other products. For example, the marginal-utility schedule for product C is independent of the amount of A and B purchased by the consumer.

From the innovating firm's perspective, these "dollar votes" represent new product demand that yields increased revenue. When per-unit revenue exceeds per-unit cost, the product innovation creates per-unit profit. Total profit rises by the per-unit profit multiplied by the number of units sold. As a percentage of the original R&D expenditure, the rise in total profit is the return on that R&D expenditure. It was the basis for the expected-rate-of-return curve *r* in Figure 11W.4.

Other related points:

- ***Importance of price*** Consumer acceptance of a new product depends on both its marginal utility and its price. (Confirm that the consumer represented in Table 11W.1 would buy zero units of new product C if its price were $8 rather than $4.) To be successful, a new product must not only deliver utility to consumers but do so at an acceptable price.
- ***Unsuccessful new products*** For every successful new product, hundreds do not succeed; the expected return that motivates product innovation is not always realized. Examples of colossal product flops are Ford's Edsel automobile, quadraphonic stereo, New Coke by Coca-Cola, Kodak disc cameras, and XFL football. Less dramatic failures include the hundreds of "dot-com" firms that have gone out of business in the last decade. In each case, millions of dollars of R&D and promotion expense ultimately resulted in loss, not profit.
- ***Product improvements*** Most product innovation consists of incremental improvements to existing products rather than radical inventions. Examples: more fuel-efficient automobile engines, new varieties of pizza, lighter-weight shafts for golf clubs, more flavorful bubble-gum, "rock shocks" for mountain bikes, and clothing made of wrinkle-free fabrics. **(Key Question 6)**

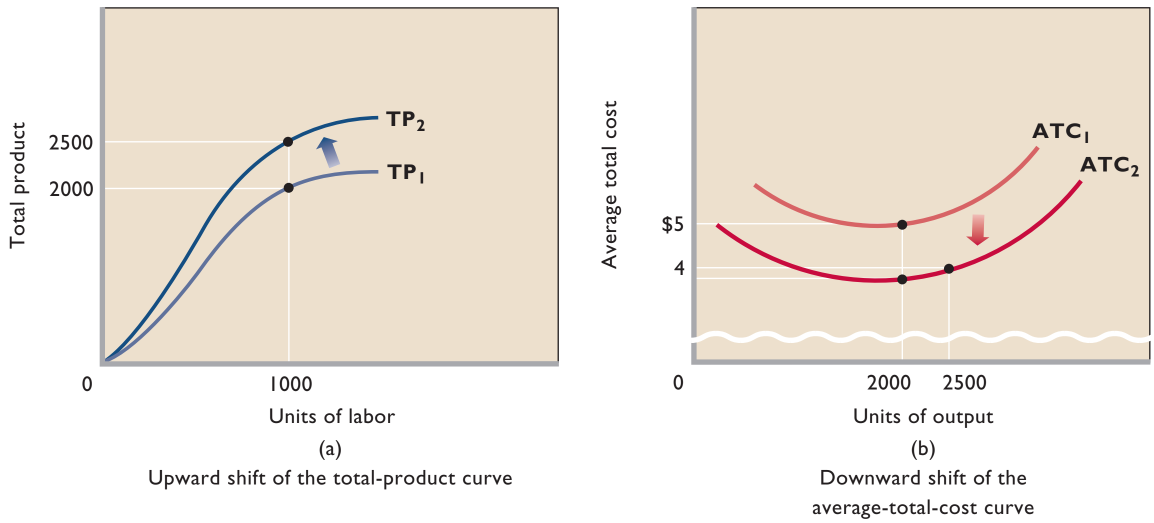
Reduced Cost via Process Innovation

The introduction of better methods of producing products—process innovation—is also a path toward enhanced profit and a positive return on R&D expenditures. Suppose a firm introduces a new and better production process, say, assembling its product by teams rather than by a standard assembly line. Alternatively, suppose this firm replaces old equipment with more productive equipment embodying technological advance. In either case, the innovation yields an upward shift in the firm's total-product curve from TP_1 to TP_2 in Figure 11W.5a. Now more units of output can be produced at each level of resource usage. Note from the figure, for example, that this firm can now produce 2500 units of output, rather than 2000 units, when using 1000 units of labor. So its average product has increased from 2 (= 2000 units of output/1000 units of labor) to 2.5 (= 2500 units of output/1000 units of labor).

The result is a downward shift in the firm's average-total-cost curve, from ATC_1 to ATC_2 in Figure 11W.5b. To understand why, let's assume this firm pays $1000 for the use of its capital and $9 for each unit of labor. Since it uses 1000 units of labor, its labor cost is $9000 (= $9 × 1000); its capital cost is $1000; and thus its total cost is $10,000. When its output increases from 2000 to 2500 units as a result of the process innovation, its total cost remains $10,000. So its average total cost declines from $5 (= $10,000/2000) to $4 (= $10,000/2500). Alternatively, the firm could produce the original 2000 units of output with fewer units of labor at an even lower average total cost.

This reduction in average total cost enhances the firm's profit. As a percentage of the R&D expenditure that fostered it, this extra profit is the expected return *r*, the basis for the rate-of-return curve in Figure 11W.3. In this case, the expected rate of return arose from the

FIGURE 11W.5 Process innovation, total product, and average total cost. (a) Process innovation shifts a firm's total-product curve upward from TP_1 to TP_2, meaning that with a given amount of capital the firm can produce more output at each level of labor input. As shown, with 1000 units of labor it can produce 2500 rather than 2000 units of output. (b) The upward shift in the total-product curve results in a downward shift in the firm's average-total-cost curve, from ATC_1 to ATC_2. This means the firm can produce any particular unit of output at a lower average total cost than it could previously. For example, the original 2000 units can be produced at less than $4 per unit, versus $5 per unit originally. Or 2500 units can now be produced at $4 per unit.



WORKED PROBLEMS
W 11W.2
Process innovation

prospect of lower production costs through process innovation.

Example: Computer-based inventory control systems, such as those pioneered by Wal-Mart, enabled innovators to reduce the number of people keeping track of inventories and placing reorders of sold goods. They also enabled firms to keep goods arriving "just in time," reducing the cost of storing inventories. The consequence? Significant increases in sales per worker, declines in average total cost, and increased profit. **(Key Question 8)**

Imitation and R&D Incentives

Our analysis of product and process innovation explains how technological advance enhances a firm's profit. But it also hints at a potential **imitation problem:** A firm's rivals may be able to imitate its new product or process, greatly reducing the originator's profit from its R&D effort. As just one example, in the 1980s U.S. auto firms took apart Japanese Honda Accords, piece by piece, to discover the secrets of their high quality. This reverse engineering—which ironically was perfected earlier by the Japanese—helped the U.S. firms incorporate innovative features into their own cars. This type of imitation is perfectly legitimate and fully anticipated; it is often the main path to widespread diffusion of an innovation.

In fact, a dominant firm that is making large profits from its existing products may let smaller firms in the industry incur the high costs of product innovation while it closely monitors their successes and failures. The dominant firm then moves quickly to imitate any successful new product; its goal is to become the second firm to embrace the innovation. In using this so-called **fast-second strategy,** the dominant firm counts on its own product-improvement abilities, marketing prowess, or economies of scale to prevail.

Examples abound: Royal Crown introduced the first diet cola, but Diet Coke and Diet Pepsi dominate diet-cola sales today. Meister-Brau introduced the first low-calorie beer, but Miller popularized the product with its Miller Lite. Gillette moved quickly with its own stainless-steel razor blade only after a smaller firm, Wilkinson, introduced this product innovation. Creative Technology (the maker of Sound Blaster audio cards for personal computers) introduced the first miniature MP3 player, but Apple popularized the product with its iPod.

Benefits of Being First

Imitation and the fast-second strategy raise an important question: What incentive is there for any firm to bear the expenses and risks of innovation if competitors can imitate its new or improved product? Why not let others bear the costs and risks of product development and then just imitate the successful innovations? Although we have seen that this may be a plausible strategy in some situations, there are several protections for, and potential advantages to, taking the lead.

Patents Some technological breakthroughs, specifically inventions, can be patented. Once patented, they cannot be legally imitated for two decades from time of patent application. The purpose of patents is, in fact, to reduce imitation and its negative effect on the incentive for engaging in R&D. Example: Polaroid's patent of its instant camera enabled it to earn high economic profits for many years. When Kodak "cloned" the camera, Polaroid won a patent-infringement lawsuit against its rival. Kodak not only had to stop producing its version of the camera but had to buy back the Kodak instant cameras it had sold and pay millions of dollars in damages to Polaroid.

There are hundreds of other examples of long-run profits based on U.S. patents; they involve products from prescription drugs to pop-top cans to weed trimmers. As shown in Global Perspective 11W.2, foreign citizens and firms hold U.S. patents along with American citizens and firms.

Copyrights and Trademarks *Copyrights* protect publishers of books, computer software, movies, videos, and musical compositions from having their works copied. *Trademarks* give the original innovators of products the exclusive right to use a particular product name ("M&Ms," "Barbie Doll," "Wheaties"). By reducing the problem of direct copying, these legal protections increase the incentive for product innovation. They have been strengthened worldwide through recent international trade agreements.

GLOBAL PERSPECTIVE 11W.2

Distribution of U.S. Patents, by Foreign Nation

Foreign citizens, corporations, and governments hold 41 percent of U.S. patents. The top 10 foreign countries in terms of U.S. patent holdings since 1963 are listed below, with the number of U.S. patents (through 2006) in parentheses.

Top 10 Foreign Countries

- Japan (658,827)
- Germany (295,110)
- U. K. (123,371)
- France (110,839)
- Canada (77,594)
- Taiwan (58,162)
- Switzerland (52,201)
- South Korea (44,125)
- Italy (43,668)
- Sweden (38,456)

Source: U.S. Patent and Trademark Office, **www.uspto.gov.**

Brand-Name Recognition Along with trademark protection, brand-name recognition may give the original innovator a major marketing advantage for years or even decades. Consumers often identify a new product with the firm that first introduced and popularized it in the mass market. Examples: Levi's blue jeans, Kleenex soft tissues, Johnson and Johnson's Band-Aids, Sony's Walkman, and Kellogg's Corn Flakes.

Trade Secrets and Learning by Doing Some innovations involve trade secrets, without which competitors cannot imitate the product or process. Example: Coca-Cola has successfully kept its formula for Coke a secret from potential rivals. Many other firms have perfected special production techniques known only to them. In a related advantage, a firm's head start with a new product often allows it to achieve substantial cost reductions through learning by doing. The innovator's lower cost may enable it to continue to profit even after imitators have entered the market.

Time Lags Time lags between innovation and diffusion often enable innovating firms to realize a substantial economic profit. It takes time for an imitator to gain knowledge of the properties of a new innovation. And once it has that knowledge, the imitator must design a substitute product, gear up a factory for its production, and conduct a marketing campaign. Various entry barriers, such as large financial requirements, economies of scale, and price-cutting, may extend the time lag between innovation and imitation. In practice, it may take years or even decades before rival firms can successfully imitate a profitable new product and cut into the market share of the innovator. In the meantime, the innovator continues to profit.

Profitable Buyouts A final advantage of being first arises from the possibility of a buyout (outright purchase) of the innovating firm by a larger firm. Here, the innovative entrepreneurs take their rewards immediately, as cash or as shares in the purchasing firm, rather than waiting for perhaps uncertain long-run profits from their own production and marketing efforts.

Examples: Once the popularity of cellular communications became evident, AT&T bought out McCaw Communications, an early leader in this new technology. When Minnetonka's Softsoap became a huge success, it sold its product to Colgate-Palmolive. More recently, Swiss conglomerate Nestlé bought out Chef America, the highly successful maker of Hot Pockets frozen meat-and-cheese sandwiches. Such buyouts are

CONSIDER THIS . . .

Trade Secrets

Trade secrets have long played an important role in maintaining returns from research and development (R&D). Long before Coca-Cola's secret formula or Colonel Sanders' secret herbs and spices, legend has it that the Roman citizen Erasmo (c. A.D. 130) had a secret ingredient for violin strings.* As the demand for his new product grew, he falsely identified his strings as *catgut,* when they were actually made of sheep intestines. Why the deception? At the time, it was considered to be extremely bad luck to kill a cat. By identifying his strings as catgut, he hoped that nobody would imitate his product and reduce his monopoly profit. Moreover, his product name would help him preserve his valuable trade secret.

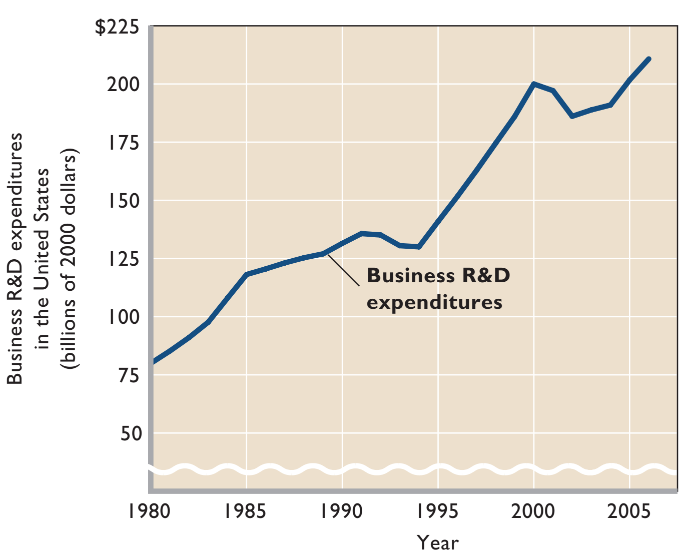
*We found this anecdote in Dennis W. Carleton and Jeffrey Perloff, *Modern Industrial Organization,* 2d ed. (New York: HarperCollins, 1994), p. 139. Their source, in turn, was L. Boyd, *San Francisco Chronicle,* October 27, 1984, p. 35.

legal under current antitrust laws as long as they do not substantially lessen competition in the affected industry. For this to be the case, there must be other strong competitors in the market. That was not true, for example, when Microsoft tried to buy out Intuit (maker of Quicken, the best-selling financial software). That buyout was disallowed because Intuit and Microsoft were the two main suppliers of financial software for personal computers.

In short, despite the imitation problem, significant protections and advantages enable most innovating firms to profit from their R&D efforts, as implied by the continuing high levels of R&D spending by firms year after year. As shown in Figure 11W.6, business R&D spending in the United States not only remains substantial but has grown over the past quarter-century. The high levels of spending simply would not continue if imitation consistently and severely depressed rates of return on R&D expenditures.

QUICK REVIEW 11W.2

- A firm's optimal R&D expenditure is the amount at which the expected rate of return (marginal benefit) from the R&D expenditure just equals the interest-rate cost of borrowing (marginal cost) required to finance it.
- Product innovation can entice consumers to substitute a new product for existing products to increase their total utility, thereby increasing the innovating firm's revenue and profit.
- Process innovation can lower a firm's production costs and increase its profit by increasing total product and decreasing average total cost.
- A firm faces reduced profitability from R&D if competitors can successfully imitate its new product or process. Nevertheless, there are significant potential protections and benefits to being first, including patents, copyrights, and trademarks; brand-name recognition; trade secrets; cost reductions from learning by doing; and major time lags between innovation and imitation.



Source: National Science Foundation, **www.nsf.gov.**

FIGURE 11W.6 The growth of business R&D expenditures in the United States, 1980–2006. Inflation-adjusted R&D expenditures by firms are substantial and growing, suggesting that R&D continues to be profitable for firms, even in the face of possible imitation.

Role of Market Structure

In view of our discussion of market structures in the last three chapters, asking whether some particular market structure or firm size is best suited to technological progress is logical. Is a highly competitive industry consisting of thousands of relatively small firms preferable to an industry comprising only two or three large firms? Or is some intermediate structure best?

Market Structure and Technological Advance

As a first step toward answering these questions, we survey the strengths and shortcomings of our four market models as related to technological advance.

Pure Competition Does a pure competitor have a strong incentive and strong ability to undertake R&D? On the positive side, strong competition provides a reason for such firms to innovate; competitive firms tend to be less complacent than monopolists. If a pure competitor does not seize the initiative, one or more rivals may introduce a new product or cost-reducing production technique that could drive it from the market. As a matter of short-term profit and long-term survival, the pure competitor is under continual pressure to improve products and lower costs through innovation. Also, where there are many competing firms, there is less chance that an idea for improving a product or process will be overlooked by a single firm.

On the negative side, the expected rate of return on R&D may be low or even negative for a pure competitor. Because of easy entry, its profit rewards from innovation may quickly be competed away by existing or entering firms that also produce the new product or adopt the new technology. Also, the small size of competitive firms and the fact that they earn only a normal profit in the long run lead to serious questions as to whether they can finance substantial R&D programs. Observers have noted that the high rate of technological advance in the purely competitive agricultural industry, for example, has come not from the R&D of individual farmers but from government-sponsored research and from the development of fertilizers, hybrid seed, and farm implements by oligopolistic firms.

Monopolistic Competition Like pure competitors, monopolistic competitors cannot afford to be complacent. But unlike pure competitors, which sell standardized products, monopolistic competitors have a strong profit incentive to engage in product innovation. This incentive to differentiate products from those of competitors stems from the fact that sufficiently novel products may create monopoly power and thus economic profit. There are many examples of innovative firms (McDonald's, Blockbuster Video, Starbuck's Coffee Company) that started out as monopolistic competitors in localized markets but soon gained considerable national market power, with the attendant economic profit.

For the typical firm, however, the shortcomings of monopolistic competition in relation to technological advance are the same as those of pure competition. Most monopolistic competitors remain small, which limits their ability to secure inexpensive financing for R&D. In addition, monopolistic competitors find it difficult to extract large profits from technological advances. Any economic profits from innovation are usually temporary because entry to monopolistically competitive industries is relatively easy. In the long run, new entrants with similar goods reduce the demand for the innovator's product, leaving the innovator with only a normal profit. Monopolistic competitors therefore usually have relatively low expected rates of return on R&D expenditures.

Oligopoly Many of the characteristics of oligopoly are conducive to technological advance. First, the large size of oligopolists enables them to finance the often large R&D costs associated with major product or process innovation. In particular, the typical oligopolist realizes an ongoing economic profit, a part of which is retained. This undistributed profit serves as a major source of readily available, relatively low-cost funding for R&D. Moreover, the existence of barriers to entry gives the oligopolist some assurance that it can maintain any economic profit it gains from innovation. Then, too, the large sales volume of the oligopolist enables it to spread the cost of specialized R&D equipment and teams of specialized researchers over a great many units of output. Finally, the broad scope of R&D activity within oligopolistic firms helps them offset the inevitable R&D "misses" with more-than-compensating R&D "hits." Thus, oligopolists clearly have the means and incentive to innovate.

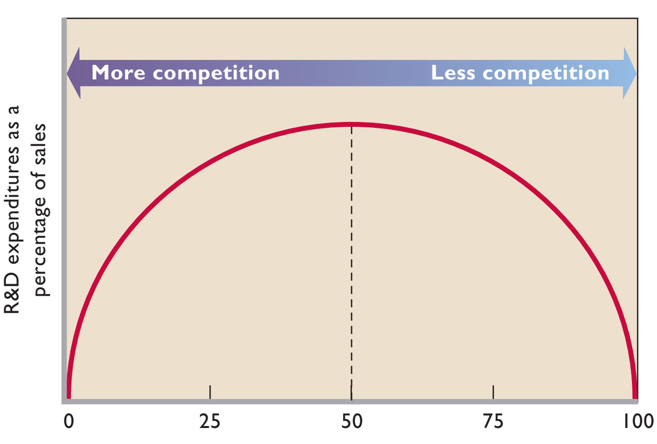
But there is also a negative side to R&D in oligopoly. In many instances, the oligopolist's incentive to innovate may be far less than we have implied above because oligopoly tends to breed complacency. An oligopolist may reason that introducing costly new technology and producing new products makes little sense when it currently is earning a sizable economic profit without them. The oligopolist wants to maximize its profit by exploiting fully all its capital assets. Why rush to develop a new product (say, batteries for electric automobiles) when that product's success will render obsolete much of the firm's current equipment designed to produce its existing product (say, gasoline engines)? It is not difficult to cite oligopolistic industries in which the largest firms' interest in R&D has been quite modest. Examples: the steel, cigarette, and aluminum industries.

Pure Monopoly In general, the pure monopolist has little incentive to engage in R&D; it maintains its high profit through entry barriers that, in theory, are complete. The only incentive for the pure monopolist to engage in R&D is defensive: to reduce the risk of being blindsided by some new product or production process that destroys its monopoly. If such a product is out there to be discovered, the monopolist may have an incentive to find it. By so doing, it can either exploit the new product or process for continued monopoly profit or suppress the product until the monopolist has extracted the maximum profit from its current capital assets. But, in general, economists agree that pure monopoly is the market structure least conducive to innovation.

Inverted-U Theory of R&D

Analysis like this has led some experts on technological progress to postulate a so-called **inverted-U theory of R&D,** which deals with the relationship between market structure and technological advance. This theory is illustrated in Figure 11W.7, which relates R&D spending as a percentage of a firm's sales (vertical axis) to the industry's four-firm concentration ratio (horizontal axis). The "inverted-U" shape of the curve suggests that R&D effort is at best weak in both very-low-concentration industries (pure competition) and very-high-concentration industries (pure monopoly). Starting from the lowest concentrations, R&D spending as a percentage of sales rises with concentration until a concentration ratio of 50 percent or so is reached, meaning that the four largest firms account for about one-half the total industry output. Beyond that, relative R&D spending decreases as concentration rises.

FIGURE 11W.7 The inverted-U theory of R&D expenditures. The inverted-U theory suggests that R&D expenditures as a percentage of sales rise with industry concentration until the four-firm concentration ratio reaches about 50 percent. Further increases in industry concentration are associated with lower relative R&D expenditures.



The logic of the inverted-U theory follows from our discussion. Firms in industries with very low concentration ratios are mainly competitive firms. They are small, and this makes it difficult for them to finance R&D. Moreover, entry to these industries is easy, making it difficult to sustain economic profit from innovations that are not supported by patents. As a result, firms in these industries spend little on R&D relative to their sales. At the other end (far right) of the curve, where concentration is exceptionally high, monopoly profit is already high and innovation will not add much more profit. Furthermore, innovation typically requires costly retooling of very large factories, which will cut into whatever additional profit is realized. As a result, the expected rate of return from R&D is quite low, as are expenditures for R&D relative to sales. Finally, the lack of rivals makes the monopolist quite complacent about R&D.

The optimal industry structure for R&D is one in which expected returns on R&D spending are high and funds to finance it are readily available and inexpensive. From our discussion, those factors seem to occur in industries where a few firms are absolutely and relatively large but where the concentration ratio is not so high as to prohibit vigorous competition by smaller rivals. Rivalry among the larger oligopolistic firms and competition between the larger and the smaller firms then provide a strong incentive for R&D. The inverted-U theory of R&D, as represented by Figure 11W.7, also points toward this "loose" oligopoly as the optimal structure for R&D spending.

Market Structure and Technological Advance: The Evidence

Various industry studies and cross-industry studies collectively support the inverted-U theory of R&D.[1] Other things equal, the optimal market structure for technological advance seems to be an industry in which there is a mix of large oligopolistic firms (a 40 to 60 percent concentration ratio), with several highly innovative smaller firms.

But our "other-things-equal" qualification is quite important here. Whether or not a particular industry is highly technical may well be a more important determinant of R&D than its structure. While some concentrated industries (electronics, aircraft, and petroleum) devote large quantities of resources to R&D and are very innovative, others (cigarettes, aluminum, gypsum products) are not. The level of R&D spending within an industry seems to depend as much on its technical character and "technological

[1]One such recent study is that by Philippe Aghion et al., "Competition and Innovation: An Inverted-U Relationship," *Quarterly Journal of Economics*, May 2005, pp. 701–728.

opportunities" as on its market structure. There simply may be more opportunities to innovate in the computer and pharmaceutical industries, for example, than in the brick-making and coal-mining industries.

Conclusion: The inverted-U curve shown in Figure 11W.7 is a useful depiction of the general relationship between R&D spending and market structure, other things equal.

Technological Advance and Efficiency

Technological advance contributes significantly to economic efficiency. New and better processes and products enable society to produce more output, as well as a higher-valued mix of output.

Productive Efficiency

Technological advance as embodied in process innovation improves *productive efficiency* by increasing the productivity of inputs (as indicated in Figure 11W.5a) and by reducing average total costs (as in Figure 11W.5b). In other words, it enables society to produce the same amount of a particular good or service while using fewer scarce resources, thereby freeing the unused resources to produce other goods and services. Or if society desires more of the now less expensive good, process innovation enables it to have that greater quantity without sacrificing other goods. Viewed either way, process innovation enhances productive efficiency: It reduces society's per-unit cost of whatever mix of goods and services it chooses. It thus is an important means of shifting an economy's production possibilities curve rightward.

Allocative Efficiency

Technological advance as embodied in *product* (or service) innovation enhances allocative efficiency by giving society a more preferred mix of goods and services. Recall from our earlier discussion that consumers buy a new product rather than an old product only when buying the new one increases the total utility obtained from their limited incomes. Obviously, then, a popular new product—and the new mix of products it implies—creates a higher level of total utility for society.

In terms of markets, the demand for the new product rises and the demand for the old product declines. The high economic profit engendered by the new product attracts resources away from less valued uses and to the production of the new product. In theory, such shifting of resources continues until the price of the new product equals its marginal cost.

There is a caveat here, however. Innovation (either product or process) can create monopoly power through patents or through the many advantages of being first. When new monopoly power results from an innovation, society may lose part of the improved efficiency it otherwise would have gained from that innovation. The reason is that the profit-maximizing monopolist restricts output to keep its product price above marginal cost. For example, Microsoft's innovative Windows product has resulted in dominance in the market for Intel-compatible operating systems for personal computers. Microsoft's substantial monopoly power permits it to charge prices that are well above marginal cost and minimum average total cost.

Creative Destruction

Although innovation can create monopoly power, it also can reduce or eliminate it. By increasing competition where it previously was weak, innovation can push prices down toward marginal cost. For example, Intel's microprocessor enabled personal computers, and their ease of production eventually diminished IBM's monopoly power in the sale of computer hardware. More recently, Linux's new computer operating system has provided some promising competition for Microsoft Windows.

At the extreme, innovation may cause **creative destruction,** where the creation of new products and new production methods simultaneously destroys the monopoly market positions of firms committed to existing products and old ways of doing business. As stated many years ago by Joseph Schumpeter, who championed this view:

> In capitalist reality . . . it is . . . competition from the new commodity, the new technology, the new source of supply, the new type of business organization—competition which commands a decisive cost or quality advantage and which strikes not at the margins of profits of the existing firms but at their foundation and their very lives. This kind of competition is . . . so . . . important that it becomes a matter of comparative indifference whether competition in the ordinary sense functions more or less promptly; the powerful lever that in the [very] long run expands output and brings down prices is in any case made of other stuff.[2]

There are many examples of creative destruction: In the 1800s wagons, ships, and barges were the only means of transporting freight until the railroads broke up their monopoly; the dominant market position of the railroads was, in turn, undermined by trucks and, later, by airplanes. Movies brought new competition to live theater, at one time the "only show in town," but movies

[2]Joseph A. Schumpeter, *Capitalism, Socialism, and Democracy*, 3d ed. (New York: Harper & Row, 1950), pp. 84–85.

LAST Word

On the Path to the Personal Computer and Internet

Technological Advance Is Clearly Evident in the Development of the Modern Personal Computer and the Emergence of the Internet. Here Is a Brief History of Those Events.

1945 Grace Murray Hopper finds a dead moth between relay contacts in the experimental Mark II computer at Harvard University. Whenever the computer subsequently malfunctions, workers set out to "debug" the device.

1946 ENIAC is revealed. A precursor to the modern-day computer, it relies on 18,000 vacuum tubes and fills 3000 cubic feet of space.

1947 AT&T scientists invent the "transfer resistance device," later known as the transistor. It replaces the less reliable vacuum tubes in computers.

1961 Bob Noyce (who later founded Intel Corporation) and Jack Kilby invent the first integrated circuit, which miniaturizes electronic circuitry onto a single silicon chip.

1964 IBM introduces the System/360 computer. Configured as a system, it takes up nearly the same space as two tennis courts.

1965 Digital Equipment Corporation unveils its PDP-8, the first relatively small-size computer (a "minicomputer").

1969 A networking system called ARPANET is born; it is the beginning of the Internet.

1971 Intel introduces its 4004 processor (a "microprocessor"). The $200 chip is the size of a thumbnail and has as much computing capability as the earlier ENIAC.

1975 Xerox markets Alto, the first personal computer (a "microcomputer"). Bill Gates and Paul Allen found Microsoft. MITS Corporation's Altair 8800 arrives on the scene. It contains Intel's 8080 microprocessor that Intel developed a year earlier to control traffic lights.

1977 Apple II, Commodore's PET, and Tandy Radio Shack TRS-80 go on sale, setting the stage for the personal computer revolution.

1981 IBM enters the market with its personal computer powered by the Intel 8800 chip and operated by the Microsoft Disc Operating System (MS-DOS). Osborne Computer markets the Osborne 1, the first self-contained microcomputer, but within 2 years the firm declares bankruptcy. Logitech commercializes the "X-Y Position Indicator for a Display System," invented earlier by Douglas Engelbart in a government-funded research lab. Someone dubs it a "computer mouse" because it appears to have a tail.

1982 Compaq Computer "clones" the IBM machines; others do the same. Eventually Compaq becomes one of the leading sellers of personal computers.

1984 Apple introduces its Macintosh computer, with its "user-friendly" icons, attached mouse, and preloaded software. College student Michael Dell founds Dell Computers, which builds personal computers and sells them through mail order. IBM, Sears Roebuck, and CBS team up to launch Prodigy Services, the first online computer business.

1985 Microsoft releases its Windows graphical interface operating system that improves upon MS-DOS. Ted Waitt starts a mail-order personal computer business (Gateway 2000) out of his South Dakota barn.

were later challenged by television. Vinyl long-playing records supplanted acetate 78-rpm phonograph records; cassettes then challenged LP records; and compact discs undermined cassettes. Now iPods, MP3 players, and Internet music downloads threaten sales of traditional CDs. Aluminum cans and plastic bottles have displaced glass bottles in many uses. E-mail has challenged the postal service. Mass discounters such as Wal-Mart and Costco have gained market share at the expense of Sears and Montgomery Ward.

ORIGIN OF THE IDEA

O 11W.1

Creative destruction

According to Schumpeter, an innovator will automatically displace any monopolist that no longer delivers superior performance. But many contemporary economists think this notion reflects more wishful thinking than fact. In this view, the idea that creative destruction is automatic

> . . . neglects the ability of powerful established firms to erect private storm shelters—or lobby government to build public storm shelters for them—in order to shield themselves from

1990 Microsoft introduces Windows 3.0, which, like Macintosh, features windows, icons, and pull-down menus. Apple sues Microsoft for copyright infringement.

1991 The World Wide Web (an Internet system) is invented.

1993 Intel introduces its first of several Pentium chips, which greatly speed up computing. The courts reject Apple's claim that Microsoft violated its copyrights on its Macintosh operating system.

1994 Marc Andreessen starts up Netscape Communications and markets Netscape Navigator, which quickly becomes the leading software browser for the emerging Internet. David Filo and Jerry Yang develop Yahoo, a system for locating material stored on the Internet.

1995 Microsoft releases the Windows 95 operating system, which becomes the dominant operating system of personal computers (90 percent market share). Microsoft is now well established as the world's leading software producer. Sun Microsystems introduces Java, an Internet programming language.

1996 Playing catch-up with Netscape, Microsoft develops Microsoft Internet Explorer and gives it away free.

1999 Netscape's market share plunges and it merges with America Online. More than 100 million personal computers are manufactured worldwide this year alone.

2000 Sixty percent of American households have access to the Internet either at home or at work, and the Internet spreads worldwide. Internet commerce in the United States reaches $300 billion, and an estimated 1.2 million U.S. jobs are Internet-related.

2002 A Federal court of appeals finds that Microsoft has a monopoly in operating system software for Intel-compatible personal computers and has maintained its monopoly through illegal actions aimed at thwarting threats from rivals. The court imposes a set of specific restrictions on Microsoft's anti-competitive business practices.

2005 Google, the innovative Internet search company, becomes the "darling" of Wall Street as its share price rises from $85 at its initial public offering (IPO) in August 2004 to $700 at the end of 2007.

Source: Based partly on Diedtra Henderson, "Moore's Law Still Reigns," *Seattle Times*, Nov. 24, 1996, augmented and updated.

the Schumpeterian gales of creative destruction. It ignores the difference between the legal freedom of entry and the economic reality deterring the entry of potential newcomers into concentrated industries.[3]

That is, some dominant firms may be able to use strategies such as selective price cutting, buyouts, and massive advertising to block entry and competition from even the most innovative new firms and existing rivals. Moreover, politically active dominant firms have been known to persuade government to give them tax breaks, subsidies, and tariff protection that strengthen their market power.

In short, while innovation in general enhances economic efficiency, in some cases it may lead to entrenched monopoly power. Further innovation may eventually destroy that monopoly power, but the process of creative destruction is neither automatic nor inevitable. On the other hand, the possession of monopoly power does not necessarily preclude rapid technological advance, innovation, or efficiency.

[3]Walter Adams and James Brock, *The Structure of American Industry*, 10th ed. (Upper Saddle River, N.J.: Prentice Hall, 2001), pp. 363–364.

Summary

1. Technological advance is evidenced by new and improved goods and services and new and improved production or distribution processes. In economists' models, technological advance occurs only in the *very long run*.
2. Invention is the discovery of a product or process through the use of imagination, ingenuity, and experimentation. Innovation is the first successful commercial introduction of a new product, the first use of a new method, or the creation of a new form of business enterprise. Diffusion is the spread of an earlier innovation among competing firms. Firms channel a majority of their R&D expenditures to innovation and imitation, rather than to basic scientific research and invention.
3. Historically, most economists viewed technological advance as a random, external force to which the economy adjusted. Many contemporary economists see technological advance as occurring in response to profit incentives within the economy and thus as an integral part of capitalism.
4. Entrepreneurs and other innovators try to anticipate the future. They play a central role in technological advance by initiating changes in products and processes. Entrepreneurs often form start-up firms that focus on creating and introducing new products. Sometimes, innovators work in the R&D labs of major corporations. Entrepreneurs and innovative firms often rely heavily on the basic research done by university and government scientists.
5. A firm's optimal amount of R&D spending occurs where its expected return (marginal benefit) from the R&D equals its interest-rate cost of funds (marginal cost) to finance the R&D. Entrepreneurs and firms use several sources to finance R&D, including (a) bank loans, (b) bonds, (c) venture capital (funds lent in return for a share of the profits if the business succeeds), (d) undistributed corporate profits (retained earnings), and (e) personal savings.
6. Product innovation, the introduction of new products, succeeds when it provides consumers with higher marginal utility per dollar spent than do existing products. The new product enables consumers to obtain greater total utility from a given income. From the firm's perspective, product innovation increases net revenue sufficiently to yield a positive rate of return on the R&D spending that produced the innovation.
7. Process innovation can lower a firm's production costs by improving its internal production techniques. Such improvement increases the firm's total product, thereby lowering its average total cost and increasing its profit. The added profit provides a positive rate of return on the R&D spending that produced the process innovation.
8. Imitation poses a potential problem for innovators since it threatens their returns on R&D expenditures. Some dominant firms use a fast-second strategy, letting smaller firms initiate new products and then quickly imitating the successes. Nevertheless, there are significant protections and potential benefits for firms that take the lead with R&D and innovation, including (a) patent protection, (b) copyrights and trademarks, (c) lasting brand-name recognition, (d) benefits from trade secrets and learning by doing, (e) high economic profits during the time lag between a product's introduction and its imitation, and (f) the possibility of lucrative buyout offers from larger firms.
9. Each of the four basic market structures has potential strengths and weaknesses regarding the likelihood of R&D and innovation. The inverted-U theory of R&D holds that a firm's R&D spending as a percentage of its sales rises with its industry four-firm concentration ratio, reaches a peak at a 50 percent concentration ratio, and then declines as concentration increases further. Empirical evidence is not clear-cut but lends general support to this theory. For any specific industry, however, the technological opportunities that are available may count more than market structure in determining R&D spending and innovation.
10. In general, technological advance enhances both productive and allocative efficiency. But in some situations patents and the advantages of being first with an innovation can increase monopoly power. While in some cases creative destruction eventually destroys monopoly, most economists doubt that this process is either automatic or inevitable.

Terms and Concepts

technological advance
very long run
invention
patent
innovation
product innovation
process innovation
diffusion
start-ups
venture capital
interest-rate cost-of-funds curve
expected-rate-of-return curve
optimal amount of R&D
imitation problem
fast-second strategy
inverted-U theory of R&D
creative destruction

Study Questions

1. What is meant by technological advance, as broadly defined? How does technological advance enter into the definition of the very long run? Which of the following are examples of technological advance, and which are not: an improved production process; entry of a firm into a profitable purely competitive industry; the imitation of a new production process by another firm; an increase in a firm's advertising expenditures? **LO1**
2. Listed below are several possible actions by firms. Write "INV" beside those that reflect invention, "INN" beside those that reflect innovation, and "DIF" beside those that reflect diffusion. **LO1**
   a. An auto manufacturer adds "heated seats" as a standard feature in its luxury cars to keep pace with a rival firm whose luxury cars already have this feature.
   b. A television production company pioneers the first music video channel.
   c. A firm develops and patents a working model of a self-erasing whiteboard for classrooms.
   d. A lightbulb firm is the first to produce and market lighting fixtures with halogen lamps.
   e. A rival toy maker introduces a new Jenny doll to compete with Mattel's Barbie doll.
3. Contrast the older and the modern views of technological advance as they relate to the economy. What is the role of entrepreneurs and other innovators in technological advance? How does research by universities and government affect innovators and technological advance? Why do you think some university researchers are becoming more like entrepreneurs and less like "pure scientists"? **LO2**
4. **KEY QUESTION** Suppose a firm expects that a $20 million expenditure on R&D will result in a new product that will increase its revenue by a total of $30 million 1 year from now. The firm estimates that the production cost of the new product will be $29 million. **LO3**
   a. What is the expected rate of return on this R&D expenditure?
   b. Suppose the firm can get a bank loan at 6 percent interest to finance its $20 million R&D project. Will the firm undertake the project? Explain why or why not.
   c. Now suppose the interest-rate cost of borrowing, in effect, falls to 4 percent because the firm decides to use its own retained earnings to finance the R&D. Will this lower interest rate change the firm's R&D decision? Explain.
5. **KEY QUESTION** Answer the following lettered questions on the basis of the information in this table: **LO3**

Amount of R&D, Millions	Expected Rate of Return on R&D, %
$10	16
20	14
30	12
40	10
50	8
60	6

   a. If the interest-rate cost of funds is 8 percent, what will be the optimal amount of R&D spending for this firm?
   b. Explain why $20 million of R&D spending will not be optimal.
   c. Why won't $60 million be optimal either?
6. **KEY QUESTION** Refer to Table 11W.1 and suppose the price of new product C is $2 instead of $4. How does this affect the optimal combination of products A, B, and C for the person represented by the data? Explain: "The success of a new product depends not only on its marginal utility but also on its price." **LO3**
7. Learning how to use software takes time. So once customers have learned to use a particular software package, it is easier to sell them software upgrades than to convince them to switch to new software. What implications does this have for expected rates of return on R&D spending for software firms developing upgrades versus firms developing imitative products? **LO4**
8. **KEY QUESTION** Answer the following questions on the basis of this information for a single firm: total cost of capital = $1000; price paid for labor = $12 per labor unit; price paid for raw materials = $4 per raw-material unit. **LO3**
   a. Suppose the firm can produce 5000 units of output by combining its fixed capital with 100 units of labor and 450 units of raw materials. What are the total cost and average total cost of producing the 5000 units of output?
   b. Now assume the firm improves its production process so that it can produce 6000 units of output by combining its fixed capital with 100 units of labor and 450 units of raw materials. What are the total cost and average cost of producing the 6000 units of output?
   c. Refer to your answers to 8*a* and 8*b* and explain how process innovation can improve economic efficiency.
9. Why might a firm making a large economic profit from its existing product employ a fast-second strategy in relationship to new or improved products? What risks does it run in pursuing this strategy? What incentive does a firm have to engage in R&D when rivals can imitate its new product? **LO4**

10. Do you think the overall level of R&D would increase or decrease over the next 20 to 30 years if the lengths of new patents were extended from 20 years to, say, "forever"? What if the duration were reduced from 20 years to, say, 3 years? **LO4**

11. Make a case that neither pure competition nor pure monopoly is conducive to a great deal of R&D spending and innovation. Why might oligopoly be more favorable to R&D spending and innovation than either pure competition or pure monopoly? What is the inverted-U theory of R&D, and how does it relate to your answers to these questions? **LO5**

12. Evaluate: "Society does not need laws outlawing monopolization and monopoly. Inevitably, monopoly causes its own self-destruction since its high profit is the lure for other firms or entrepreneurs to develop substitute products." **LO6**

13. **LAST WORD** Identify a specific example of each of the following in this chapter's Last Word: (*a*) entrepreneurship, (*b*) invention, (*c*) innovation, and (*d*) diffusion.

Web-Based Questions

1. **THE NATIONAL SCIENCE FOUNDATION R&D STATISTICS—WHAT'S HAPPENING?** Go to the Division of Science Resource Statistics Web site, **www.nsf.gov/statistics/natlpatterns,** to find National Patterns of R&D. Select the most recent update year. Then select Full Publication. Use the historical data tables to determine whether the following R&D numbers increased, remained constant, or decreased over the last 5 years listed: (*a*) Total U.S. R&D expenditures in constant dollars, (*b*) Federal support for R&D in constant dollars, (*c*) R&D as a percentage of U.S. GDP, and (*d*) Federal support of R&D as a percentage of GDP. What are the technological implications of these figures for the United States?

2. **NASA—ARE THERE COMMERCIAL SPIN-OFFS?** Visit the Web site of NASA's Technology Transfer Office, at **www.sti.nasa.gov/tto,** to identify significant commercial benefits from secondary use of NASA technology. Search the database to find and describe five such spin-offs. How does the NASA Commercial Technology Network, **nctn.hq.nasa.gov,** move technology from the lab to the marketplace?

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