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Technology, Positive Externalities, and Public Goods

New technology changes how people live and work. Technology is the difference between horses and automobiles, between candles and electric lights, between fetching water in buckets and indoor plumbing, and between infection and antibiotics. The science fiction writer Arthur C. Clarke once said: "A sufficiently advanced technology is indistinguishable from magic." New technologies often do appear magical—until we become accustomed to them and start taking them for granted.

A small fraction of the new technologies developed in the last two centuries are shown in the timeline in Exhibit 15-1. The variety of new inventions is remarkable. Some entries involve household products: the dishwasher, the coffee pot, roller skates, frozen food, video games. Some entries involve transportation: the steamboat, the gasoline-powered car, the airplane. Other entries are medical: spray medication, anesthesia, polio vaccine, antibiotics, and the artificial heart. Still other entries focus on communication: the telegraph, the telephone, radio, Internet communication.

Every invention has its own story of discovery and development, a story that often includes a parade of characters and firms over a period of years or decades. Consider the invention of the dishwasher by Josephine Cochran in 1889. Cochran was a wealthy woman living in Illinois who was concerned that her servants often chipped her family's fine china plates while washing them. She invented a machine where the plates sat in a wooden barrel, while rollers turned them and hot, soapy water could be pumped over them. Her invention won a grand prize at the 1893 Chicago World's Fair, but commercial success took longer. Cochran's husband died, leaving her with few assets, and she started a company in the shed behind her house to make and sell her dishwashers. But at that time, soap for dishwashers was often expensive and of poor quality, so it often left a residue on

Exhibit 15-1 A Technology Timeline

1752	Lightning Rod: Benjamin Franklin invents the lightning rod
1794	Cotton Gin: Eli Whitney patents his machine to remove seeds from cotton
1803	Medication Spray: Dr. Alan de Vilbiss of Toledo, Ohio, invents a device to spray medication into the mouth and nose
1806	Coffee Pot: Benjamin Thompson, Count Rumford, invents a coffee pot with a metal sieve to strain away the grounds
1807	Steamboat: The *Clermont*, invented by Robert Fulton, steams from New York City to Albany
1809	Weaving Straw with Silk or Thread: Mary Dixon Kies becomes the first woman to receive a patent for her weaving process
1831	Reaping Machine: The McCormick Reaper for cutting grain was not an economic success for several decades
1833	Sewing Machine: Walter Hunt invents the sewing machine but loses interest and does not patent his invention. Later, Isaac Singer becomes rich from a similar machine
1834	Threshing Machine: John A. and Hiram Abial Pitts invent a machine that automatically threshes and separates grain from chaff
1840	Collapsible Metal Squeeze Tube for Artist's Paint: John Rand's invention is an immediate hit in Europe
1842	Ether Anesthesia: Crawford Williamson Long of Jefferson, Georgia, performs the first operation (removal of a tumor) using an ether-based anesthesia
1843	Vulcanized Rubber: Charles Goodyear perfects his process for "vulcanizing" rubber, so that it does not melt on hot days and freeze on cold ones
1844	Telegraph: Samuel F.B. Morse demonstrates his telegraph by sending a message to Baltimore from the chambers of the Supreme Court in Washington, DC
1845	False Teeth: Claudius Ashís invention features porcelain teeth mounted with steel springs
1859	Oil Well: Edwin Drake strikes oil at 69.5 feet below the earth's surface, and western Pennsylvania sees the world's first oil boom
1863	Four-Wheeled Roller Skates: James Plimpton of Medford, Massachusetts, makes the first practical four-wheeled roller skate
1867	Barbed Wire: Lucien B. Smith of Kent, Ohio, invents the product that will divide the American west into fenced-in plots of privately owned land
1873	Typewriter: Christopher Latham Sholes sells a prototype to Remington and Sons, gunsmiths, who begin mass production
1875	Electric Dental Drill: Be grateful to George F. Green of Kalamazoo, Michigan. Hey, it beats living with decayed teeth
1876	Telephone: Alexander Graham Bell patents the telephone
1877	Phonograph: Thomas Alva Edison, with a team of engineers, perfects a system of sound recording and transmission
1879	Incandescent Light Bulb: Thomas Edison perfects an incandescent light bulb, which will see commercial use by 1881
1882	Electric Fan: Dr. Schuyler Skaats Wheeler invents a two-bladed desk fan
1889	Dishwasher: Josephine Cochran of Shelbyville, Indiana, produces a practical dishwashing machine
1892	Gasoline-Powered Car: Frank and Charles Duryea fabricate the first gasoline-powered automobile built in the U.S.
1901	Radio Over the Ocean: Guglielmo Marconi receives first trans-Atlantic radio transmission
1902	Air Conditioning: Willis H. Carrier designs the first system to control temperature and humidity
1903	Powered Airplane Flight: At Kitty Hawk, North Carolina, Orville and Wilbur Wright take a 12-second flight
1908	Model T: Carmaker Henry Ford introduces his Model T automobile, which will be produced by an assembly line
1920	First Commercial Radio Broadcast: AM station KDKA of Pittsburgh announces that Warren Harding has been elected president
1926	Rocket Launch: Robert H. Goddard, professor of physics at Clark University in Worcester, Massachusetts, launches a liquid-fuel rocket to a height of 41 feet
1929	Frozen Food: Clarence Birdseye offers his quick-frozen foods to the public
1930	Scotch Tape: 3M introduces Scotch tape
1932	Heart Defibrillator: Dr. William Bennett Kouwenhoven develops a device for jump-starting the heart with a burst of electricity
1937	Chair Lift for Skiers: The Dollar Mountain ski resort in Sun Valley, Idaho, gets a chair lift
1947	Transistor: William Shockley invents the transistor, the guts of the modern computer
1948	Electric Guitar: Leo Fender debuts the first solid-bodied electric guitar
1951	First Commercial Computer: Eckert and Mauchly Computer Co. of Philadelphia sells UNIVAC 1 to the U.S. Census Bureau
1957	Polio Vaccine: Dr. Albert Sabin develops a polio vaccine
1958	Satellite Space Exploration: The Soviet Union launches *Sputnik*. Three months later, the U.S. launches *Explorer I*
1960	Laser: Theodore H. Maiman creates the first laser at Hughes Research Laboratories
1960	Birth Control Pill: The Food and Drug Administration approves the birth control pill for sale
1964	Operating System: IBM rolls out the OS/360, the first mass-produced computer operating system, which lets computers in the IBM 360 family run many different software programs
1970	Fiber Optics: Corning Glass announces a glass fiber that can transmit sound using pulses of light
1972	Video Game: Nolan Bushnell invents Pong, one of the first mass-produced video games
1974	Barcode: The first shipments of bar-coded products arrive in American stores
1979	Cellular Phones: The first commercial cell phone system is started in Tokyo
1981	Space Shuttle: NASA successfully launches -- and lands -- the first reusable space shuttle
1982	Artificial Heart: Dr. Robert Jarvik implants a permanent artificial heart, which keeps Barney Clark alive for 112 days
1982	First Genetically Engineered Product: Genentech gets permission to market human insulin produced through genetic engineering
1984	The Mouse: Apple Computer introduces the mouse
1990	Internet Programming Language Invented: Tim Berners-Lee invents HTTP and HTML for connecting to websites and writing webpages
1996	Cloning: "Dolly" is cloned from another sheep
2000	Sequencing the Human Gene: The chemical bases of the human gene are listed in sequence

the dishes. Moreover, a survey of women in the early twentieth century reported that they often found it enjoyable and relaxing to hand-wash dishes, so they weren't eager to purchase a dishwashing machine. But eventually, Cochrane's original company became the Kitchen Aid part of the Whirlpool Corporation in 1940. Today, about half of all U.S. households have a dishwasher.

Most inventions are motivated, at least in part, by a desire to earn a financial reward. This chapter begins by exploring the idea that an inventor typically receives only a fraction of the overall social benefit that an invention provides—with much of the benefit going to users of the invention or to other firms that can copy the idea behind the invention. Government has a variety of policies to increase the rate of return received by inventors like granting patents and subsidizing research and development. However, the ultimate goal of such public policies is not to help inventors earn high returns, but to encourage a stream of inventions that will benefit society as a whole. The case of technology illustrates a broader problem that certain investments may be beneficial to society, but it may be quite difficult for private investors to earn a reasonable rate of return from these investments. The chapter concludes by discussing how a range of goods and services like police protection and highways share certain key characteristics with new technology, and that when these key characteristics exist, the government may need to encourage or coordinate production of the good or service, rather than leaving such investments up to incentives of the market.

The Incentives for Developing New Technology

Market competition and the invention of new technology, like close but quarrelling relatives, have a complicated and unstable relationship. Market competition and technology sometimes support each other and sometimes oppose each other.

Market competition can provide an incentive for discovering new technology, because a firm can earn higher profits by finding a way to produce existing products in cheaper ways or to create products with desirable characteristics. An innovative firm knows that it will usually have at least a temporary edge over its competitors and thus an ability to earn above-normal profits for at least a time before the competitors can catch up to its innovations. Also, firms may innovate out of fear that if they aren't moving ahead, they will inevitably fall behind other competitors who are seeking out innovations.

However, in certain cases market competition can also discourage new technology. Consider a pharmaceutical firm that is planning a research project to develop a new drug. On average, it can cost $800 million and take more than a decade to discover a new drug, perform the necessary safety tests, and bring the drug to market. If the research and development effort fails—and every R&D project has some chance of failure—then the firm will suffer losses and could even be driven out of business. If the research and development project succeeds, then the firm's competitors may figure out ways of adapting and copying the underlying idea, but without having to pay the research and development costs themselves. As a result, the innovative company will bear the much higher costs of the R&D project and will enjoy at best only a small, temporary advantage over the competition—until the other firms copy their idea. Thus, a pharmaceutical firm might be willing to undertake certain research projects if the firm were guaranteed that if it succeeded, it could sell the new drug as a monopoly for at least a few years and earn sufficient profit to compensate for the costs of developing the new drug. But if that same firm must face market competition that can very quickly produce an identical product or a close substitute, the firm may decide against R&D projects of this sort.

Some Grumpy Inventors

Many inventors over the years have discovered that their inventions brought less of a return than they might have reasonably expected.

Eli Whitney (1765-1825) invented the cotton gin, a machine for separating seeds out of raw cotton. He received a patent on the cotton gin in 1794 and started a business to manufacture the machine. However, the machine was so wonderfully useful in the cotton-growing states of the American South that, rather than paying for Whitney's gin, cotton planters built their own seed-separating devices, with a few minor changes. When Whitney sued in court for patent infringement, he found that the courts in southern states would not uphold his patent rights. Whitney never patented any of his other inventions and once wrote that "an invention can be so valuable as to be worthless to the inventor."

Thomas Edison (1847-1931) still holds the record for most patents granted to an individual. However, his first invention was an automatic vote counter, and despite the social benefits of such a machine in saving time, reducing error in vote counts, and preventing voter fraud, he could not find a government that wanted to buy it. After that experience, Edison vowed that he would work only on ideas for things that people would buy. Election controversies ever since then suggest that the market incentives have been inadequate to invent easy-to-use and accurate voting machines.

Gordon Gould came up with the idea behind the laser in 1957; in fact, Gould had his research notebooks for November 1957 notarized so that he could prove when the idea had come to him. However, he put off applying for a patent, mistakenly believing that he needed to have a working laser before he could apply. By the time he did apply, other scientists had laser inventions of their own. A lengthy legal battle resulted, in which Gould had to spend $100,000 of his own money on lawyers, before he eventually received a patent for the laser in 1977. But even though when Gould received the patent, the laser seemed more like the work of a number of scientists working along intersecting and overlapping tracks, not the inspiration of a single person. The laser has had an enormous range of uses: manufacturing compact disks, eye surgery tumor removal, precision measurement, navigational instruments, chemical research, printers, and as a cutting tool in textile and metalworking industries. Perhaps most of all, the laser has revolutionized telecommunications and computer networks by allowing so much more information to be carried over fiber optic cable than could have been carried over old copper wires. Compared to the enormous social benefits of the laser, Gould received relatively little financial reward. Many of those other scientists who worked on the science leading up to lasers in the 1940s and 1950s, as well as the practical development of lasers since then, received no special benefit other than their normal salaries.

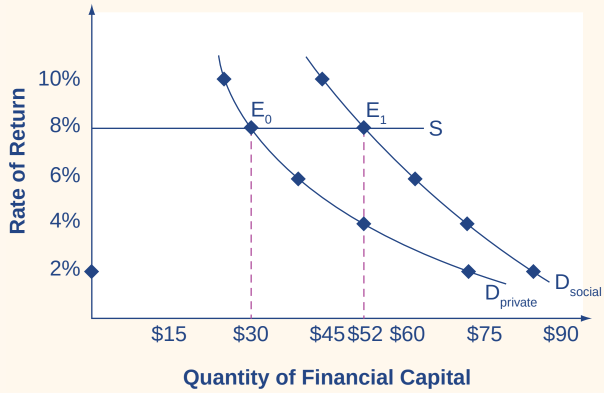
As these examples illustrate, inventors commonly receive only a portion of the total benefits of their invention. A variety of studies done by economists have found that the original inventor receives one-third to one-half of the total economic benefits from innovations, while other businesses and new product users receive the rest of the benefit.

The Positive Externalities of New Technology

If a firm builds a factory or buys a piece of equipment, the firm will receive all of the economic benefits that result from such investments. However, when a firm invests in new technology, the private benefits that the firm receives are only a portion of the overall social benefits. In economic terms, positive externalities arise—a situation where a third party benefits from the spillover effects of a market transaction by others.

Exhibit 15-2 Positive Externalities and Technology

Big Drug faces a cost of financial capital of 8%. If the firm receives only the private benefits of investing in R&D, then its demand curve for financial capital is shown by $D_{private}$, and the equilibrium will occur at a quantity of $30. However, if the firm could also receive the social benefits of its investment in R&D, then its demand curve for financial capital would be D_{social} and the equilibrium would be at a quantity of $52.



Rate of Return	$D_{Private}$	D_{Social}
2%	$72	$84
4%	$52	$72
6%	$38	$62
8%	$30	$52
10%	$26	$44

Consider the example of the Big Drug Company, which is planning its research and development budget for the next year. Economists working for Big Drug, together with scientists, have compiled a list of potential research and development projects and estimated the potential rates of return for each one. If the cost of financial capital is low, Big Drug will demand a large quantity of financial capital for research and development, because many R&D projects are likely to exceed a low rate of return. However, as cost of financial capital rises, the firm demands a lesser quantity of funding to invest in R&D, since fewer projects are likely to pay the higher rate of return. Big Drug's demand curve for financial capital to invest in R&D is shown by $D_{private}$ in Exhibit 15-2. For the sake of simplicity, say that Big Drug can borrow as much money as it wants at the prevailing market interest rate; thus, Big Drug perceives the supply curve S for financial capital as a horizontal line. At the equilibrium E_0, the quantity of financial capital that Big Drug will have invested in research and development is $30 million and the interest rate prevailing in the market is 8%.

Big Drug's original demand for financial capital $D_{private}$ is based on the private rate of return received by the firm. However, every time Big Drug makes a new discovery, other pharmaceutical firms and health care companies learn new lessons about how to treat certain medical conditions, and are then able to create their own improved (if not identical) products. If the economists at Big Drug calculated the social rate of return on its investment, say that it would be twice as high: that is, a project that had a 4% private rate of return to Big Drug actually has an 8% social return. If Big Drug was able to gain this social return, its demand for financial capital would shift to the right to the new demand curve D_{social}. The new point of equilibrium E_1 will involve spending $52 million on research and development. Thus, if Big Drug could receive a greater share of the society's total benefits from its new pharmaceuticals, it would invest more in research and development. But if Big Drug is receiving only 50 cents of each dollar of social benefit that its innovations create, then the firm won't spend as much on creating new products as if it received a greater share of the total social benefit that it is creating.

Exhibit 15-3 Positive and Negative Externalities: Parallels and Contrasts

	Negative Externality	Positive Externality
A prominent example	Pollution	Technology
Market doesn't take into account . . .	Harms incurred by third parties	Benefits received by third parties
. . . so that as a result	Too much of the negative externality is provided	Too little of the positive externality is provided
General solution	Require those who produce the negative externality to take social costs into account	Assist those who provide the positive externality to receive a greater share of the social benefits
Specific solutions	Regulations, pollution taxes, marketable permits, better-defined property rights	Government R&D spending, tax incentives for private R&D spending, intellectual property protection, allowing business co-operation on R&D

Contrasting Positive Externalities and Negative Externalities

Exhibit 15-3 summarizes the parallels and contrasts between negative and positive externalities. For a negative externality, the private costs of an action are less than the costs imposed on society as a whole, and so private actors have an incentive to carry out activities, like emitting pollution, at a level that is greater than society as a whole desires. For a positive externality, the private benefits of an action are less than the social benefits, and so private actors lack an incentive to carry out activities, like innovation that leads to new technology, to the extent that society as a whole desires.

Although technology may be the most prominent example of a positive externality, it is far from being the only one. For example, being vaccinated against disease is not only a protection for the individual, but it has the positive spillover of protecting those who might otherwise have been infected by that individual. Education clearly benefits the person who receives it, but a society where most people have a good level of education provides positive externalities for all. When one or a few homes in a neighborhood are modernized, updated, and restored, not only does it increase the value of those homes, but the value of other properties in the neighborhood may increase as well. It's also possible, instead of talking about the connection between pollution and negative externalities on its head, to flip-flop the terminology and instead to talk about the connection from anti-pollution equipment to positive externalities. Just as too much pollution exists because firms do not take negative externalities like pollution into account, one can argue that too little anti-pollution equipment is installed because firms do not take into account the positive externalities of doing so.

The last row of Exhibit 15-3 points out that appropriate response of public policy to a negative externality like pollution is to find ways so that the social costs of the negative externality are taken into account in economic decision. Conversely, the appropriate public policy response to a positive externality, like new technology, is to help the party creating the positive externality to receive a greater share of the social benefits. Practical proposals for reacting to the positive externalities of technology are discussed in the next section.

Why Are People Living Longer?

One of the most remarkable changes in the standard of living in the last several centuries is that people are living longer. Back in the Stone Ages, thousands of years ago, human life expectancies are believed to have been in the range of 20-30 years. By 1900, average life expectancy in the United States at birth was 47 years. By the start of the twenty-first century, U.S. life expectancy was 77 years. Thus, most of the gains in life expectancy in the history of the human race happened in the twentieth century.

The rise in life expectancy seems to stem from three primary factors. First, systems for providing clean water and disposing of human waste late in the nineteenth and into the twentieth century helped to prevent the transmission of many diseases. Second, changes in public behavior have advanced health. Early in the twentieth century, for example, people learned the importance of boiling bottles and milk, washing their hands, and protecting food from flies. More recent behavioral changes include reducing the number of people who smoke tobacco and precautions to limit sexually transmitted diseases. Third, medicine has played a role. Immunizations for diphtheria, cholera, pertussis, tuberculosis, tetanus, and yellow fever were developed between 1890 and 1930. Penicillin, discovered in 1941, led to a series of other antibiotic drugs for bringing infectious diseases under control. In recent decades, drugs that reduce the risks of high blood pressure have had a dramatic effect in extending lives.

These advances in public health have all been closely linked to positive externalities and public goods. Public health officials taught hygienic practices to mothers in the early 1900s and encouraged less smoking in the late 1900s. Many medical discoveries came out of government or university-funded research in the 20th century. Patents and intellectual property rights provided an additional incentive for private inventors. The reason for requiring immunizations, phrased in economic terms, is that it prevents spillovers of illness to others—as well as helping the person immunized. Many of the public sanitation systems and storm sewers were funded by government because they have the key traits of public goods.

How to Raise the Rate of Return for Innovators

A number of different mechanisms can increase the rate of return earned by inventors of new technology: intellectual property rights, government assistance with the costs of research and development, even cooperative research ventures between companies. Let us explore these policies in turn.

Intellectual Property Rights

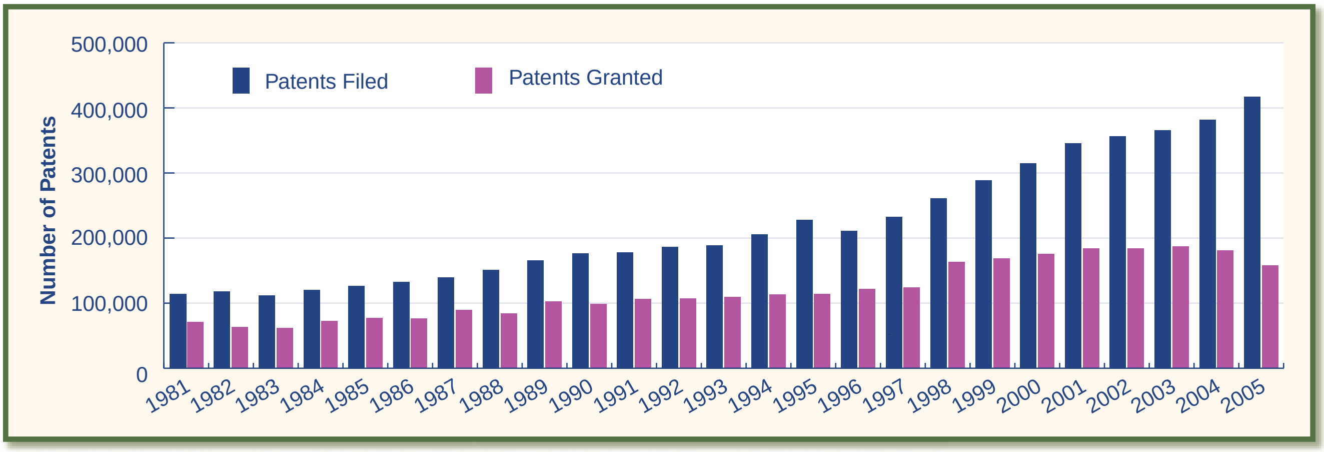
Intellectual property rights include patents, which give the inventor the exclusive legal right to make, use, or sell the invention for a limited time, and copyright laws, which give the author an exclusive legal right over works of literature, music, movies, and pictures. These topics were introduced in Chapters 11-13 in the discussions of monopoly, oligopoly and imperfect competition. For example, if a pharmaceutical firm has a patent on a new drug, then no other firm can manufacture or sell that drug, unless the firm with the patent grants permission. Without a patent, the pharmaceutical firm would have to face entry and competition for any successful products, and thus could earn no more than a normal rate of profit. But with a patent, a firm is able to earn monopoly profits on its product—which offers an incentive for research and development to take place.

intellectual property: The body of law including patents, trademarks, copyrights, and trade secret law that protect the right of inventors to produce and sell their inventions.

Exhibit 15-4 illustrates how the total number of patent applications filed with the U.S. Patent and Trademark office and the total number of patents granted has surged since the mid-1990s. Intellectual property rights do provide a method for increasing the rate of return for inventors, but there are number of reasons to doubt whether patents provide completely appropriate and sufficient incentives for innovation.

Exhibit 15-4 Patents Filed and Granted

The number of applications filed for patents increased substantially from the mid-1990s into the first half of the 2000s. The number of patents granted increased in the late 1990s, but then levelled off in the 2000s.



First, the economic studies that show that inventors receive only one-third to one-half of the total economic value of their inventions were all calculated in countries that already had patents. Thus, even with patents in place, inventors of new technology are receiving only a slice of the social value of their inventions.

Second, in a fast-moving high-technology industry like biotechnology or semiconductor design, patents may be almost irrelevant. When technology is advancing so quickly, even a patent from, say, two years ago may be completely outdated, so that no one is relying on that technology any longer. In these cases, the market forces firms to innovate as fast as they can just to keep up with others.

Third, not every new idea can be protected with a patent or a copyright. For example, a new way of organizing a factory, or a new way of training employees, or a new combination of product features may not be an "invention" in the sense that patent law uses the term. Moreover, a patent cannot cover the new ideas that it spurs others to create.

Fourth, patents and copyrights offer an incentive for research and development because they offer a temporary monopoly, which in turn allows charging a higher price for a reduced level of output. But if an alternative policy could encourage both invention and competition, instead of invention and monopoly, consumers would benefit from the lower price and greater quantity sold.

Fifth, patents may sometimes cover too much or be granted too easily. In the early 1970s, Xerox had received over 1,700 patents on various elements of the photocopy machine. Every time the Xerox improved the photocopier, it received a patent on the improvement. In the early 1970s, the U.S government charged Xerox with abusing the patent process by using this possibly ever-lasting stream of patents to block the entry of other firms into the photocopier market and to keep a permanent monopoly. In 1975, while not admitting that it had done anything wrong, Xerox agreed to allow other companies to use its patents, to drop all of its lawsuits against other companies for violating its patents, and to provide competitors with access to certain future patents. A flood of new competition followed. Xerox's market share fell from about 95 percent of the U.S. photocopier market in the early 1970s to less than half by 1980.

In recent years, questions have been raised as to whether the U.S. Patent Office is sometimes granting patents too easily. In the late 1990s, for example, the patent office

Protecting Mickey Mouse

All patents and copyrights are scheduled to end someday, and in 2003, copyright protection for Mickey Mouse was scheduled to run out. In theory, anyone would be able to copy old Mickey Mouse cartoons or draw and sell new ones. But in 1998, Congress passed the Sonny Bono Copyright Term Extension Act. It extended copyright from 50 to 70 years after an author's death and, for works produced "for hire" and owned by firms, from 75 to 95 years after publication. Along with protecting Mickey for another 20 years, the copyright extension also affected about 400,000 books, movies and songs, including books by Ernest Hemingway and songs by George Gershwin.

The act was not politically controversial; it passed the U.S. Senate with a unanimous vote. But copyright already extends 50 years after the death of the author, and it seems highly unlikely that an additional 20 years after death will provide an incentive for additional creative work. Congress voted to lengthen copyright protection because of lobbying from the firms that are continuing to benefit from these copyrighted works—the way Disney benefits from Mickey Mouse. But copyrights (and patents) were never supposed to be forever, and the social interest might have been better served by allowing broad public access to these classic works.

was granting about 20,000 new software patents per year. Many of these patents, viewed in the cold light of hindsight, look a little peculiar. For example, a firm called Priceline that sold airline tickets and other travel items received a patent on the idea that people could buy items by submitting bids over the Internet. The online retailer Amazon received a patent for the idea of being able to buy something over the Internet with one click of the mouse. Other firms have argued that these business practices are not the sort of new inventions that deserve a patent.

Sixth, the 20-year time period for a patent is somewhat arbitrary. Ideally, a patent should cover a long enough period of time for the inventor to earn a hearty return, but not so long that it allows the inventor to charge a high monopoly price permanently. The 20-year time period for patents may be too long in some cases and not long enough in others. For example, in the 1980s it was noted by pharmaceutical companies that for certain drugs, which are first patented and then need to go through years of testing before they can be broadly marketed, the typical term of a patent might result in only a few years of actual sales. Consequently, in 1984, Congress passed the Drug Price Competition and Patent Term Restoration Act to extend the patent life of brand-name drugs for five years, to make up for time lost between the original patent and the health and safety testing.

Patents serve a useful function in providing incentives for inventors. But patents are imperfect and blunt tools that usually protect only part of the value of an invention. Patents may also be granted or denied for unclear reasons: after all, many of the examiners who decide whether a patent will be granted are relatively inexperienced young lawyers who often leave the patent office after a few years for much better-paying jobs in industry. Alternative methods of improving the rate of return for inventors of new technology are desirable as well.

Government Spending on Research and Development

If the private sector does not have sufficient incentive to carry out research and development, one possible response is for the government to fund such work directly. Government provides direct financial support for research and development which is done at colleges and universities, nonprofit research entities, and sometimes by private firms, as well as at government-run laboratories.

The first column of Exhibit 15-5 shows the sources of U.S. spending on research and development; about two-thirds of R&D is funded by industry and about one-fourth by the

Exhibit 15-5 U.S. Research and Development Expenditures, 2004

Sources of R&D Funding		Where R&D Was Performed	
Federal government	$93 billion	Federal government	$25 billion
Industry	$199 billion	Industry	$222 billion
Universities/colleges	$8 billion	Universities/colleges	$50 billion
Nonprofits	$9 billion	Nonprofits	$15 billion
Nonfederal government	$3 billion		
Total	***$312 billion***	*Total*	*$312 billion*

federal government. The second column shows where the R&D is actually performed; about three-quarters of R&D is done by industry and about one-ninth by universities and colleges. When the government pays directly for a share of an R&D project, it reduces the costs of innovation for firms.

Since the 1960s, R&D spending has grown at roughly the same rate as the overall U.S. economy. However, in the 1960s the federal government paid for about two-thirds of the nation's R&D. Thus, over time, the U.S. economy has come to rely much more heavily on industry-funded R&D. The federal government has tried to focus its direct R&D spending on areas where private firms are not as active. Of the $312 billion in total R&D spending in 2004, $58 billion (about one-fifth) was classified as **basic research.** Basic research is defined as the search for fundamental scientific breakthroughs that may offer commercial applications only in distant future. The remainder of R&D is **applied research,** which is often focused on a particular product that promises an economic payoff in the short-term or the medium term. The federal government funds about half of the nation's basic R&D, much of it carried out at colleges and universities.

basic research: Research on fundamental scientific breakthroughs that may offer commercial applications only in distant future.

applied research: Research focused on a particular product that promises an economic payoff in the short- or medium-term.

Tax Breaks for Research and Development

One difficulty with direct government support of R&D is that it inevitably involves government decisions about which projects are worthy. In a political setting, the scientific question of whether research is worthwhile can easily become entangled with considerations like the location of the congressional district in which the research funding is being spent. A complementary approach to supporting R&D that does not involve the government's close scrutiny of particular R&D projects is to give firms a reduction in their taxes depending on how much research and development they so. Tax breaks to encourage R&D spending reduced the tax that would otherwise have been paid by corporations by about $9 billion in 2006, according to the U.S. Department of the Treasury.

Cooperative Research and Development

Another tool for increasing the returns to innovation was enacted by the National Cooperative Research and Production Act of 1993, which allowed companies to form jointly funded R&D institutions. When companies work together they share the expenses of R&D and share any discoveries that result. Such joint agencies offer a way for firms to share the risks of R&D as well as the benefits, rather than facing the risk that one winner-take-all innovator will get the patent and lock up the market. Before this law passed, antitrust authorities might have challenged such joint research efforts, but the new 1993 law removed that threat.

A Balancing Act

Because new technology brings positive externalities, there is a case for some sort of government action to support the development of new technology. However, each of the policies discussed here involves some balancing of interests. Patents can serve a useful role in providing incentives for inventors, but they also create temporary monopolies, they may be granted too slowly in some cases and too easily in others, and even at their best they allow the inventor to receive only a fraction of the social benefit of the invention. Government spending on research and development produces technology that is broadly available for firms to use, but it costs money to taxpayers and can sometimes be directed more for political than for scientific or economic reasons. Allowing firms to collaborate on research and development may help hold down costs, but it may also lead to a situation where firms strive less hard for new technology, since they know that any new technology will be shared, anyway. Thus, while the general case for government action to support technology and innovation is a strong one, the enactment of such programs through the political system can be controversial.

Public Goods

Even though new technology creates positive externalities, so that perhaps one-third or one-half of the social benefit of new inventions spills over to others, the inventor still receives some private return from new technology. But what about a situation where the positive externalities are so extensive that private firm producing a certain product could not expect to receive any of the social benefit at all? This kind of good is called a public good. Public goods include many items that are typically supplied to a considerable extent by government, like national defense and basic research. Let's begin by defining the characteristics of a public good, and discussing why these characteristics make it difficult for private firms to supply public goods and how government may step in to address the issue.

The Definition of a Public Good

To understand the defining characteristics of a public good, first consider an ordinary private good, like a piece of pizza. A piece of pizza can be bought and sold fairly easily because it is a separate and identifiable item. However, public goods are not separate and identifiable in this way.

Instead, **public goods** have two defining characteristics: they are **nonexcludable** and nonrivalrous. The first characteristic, that a public good is nonexcludable, means that it is costly or impossible to exclude someone from using the good. If Larry buys a private good like a piece of pizza, then he can exclude others like Lorna from eating that pizza. But if national defense is being provided, then it includes everyone. Even if you strongly disagree with America's defense policies or with the level of defense spending, the national defense still protects you. You can't choose to be unprotected, and national defense can't protect everyone else and exclude you.

The second main characteristic of a public good, that it is **nonrivalrous,** means that when one person uses the public good, another can also use it. With a private good like pizza, if Max is eating the pizza then Michelle cannot also eat it; that is, the two people are rivals in consumption. But with a public good like national defense, Max's consumption of national defense doesn't reduce the amount left for Michelle, so they are nonrivalrous in this area.

public good: A good that is nonexcludable and nonrivalrous, and thus is difficult for market producers to sell to individual consumers.

nonexcludable: When it is costly or impossible to exclude someone from using the good, and thus hard to charge for it.

nonrivalrous: A good where, when one person uses the good, others can also use it.

The Tragedy of the Commons

The historical meaning of a commons is a piece of pasture land that is open to anyone who wishes to graze their cattle upon it. More recently, the term has come to apply to any area that is open to all, like a city park. In a famous 1968 article, a professor of ecology named Garrett Hardin (1915-2003) described a scenario called the tragedy of the commons, in which the utility-maximizing behavior of individuals ruins the commons for all.

Hardin imagined a pasture that is open to many herdsmen, each with their own herd of cattle. A herdsman benefits from adding cows, but too many cows will lead to overgrazing and even to ruining the commons. The problem that when a herdsman adds a cow, the herdsman personally receives all of the gain, but when that cow contributes to overgrazing and injures the commons, the loss is suffered by all of the herdsmen as a group—so any individual herdsman suffers only a small fraction of the loss. Hardin wrote: "Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all."

This tragedy of the commons can arise in any situations where benefits are primarily received by one party, while the costs are spread out over many parties. For example, clean air can be regarded as a commons, where firms that pollute air can gain higher profits, but firms that pay for anti-pollution equipment provide a benefit to others. A commons can be regarded as a public good, where it is difficult to exclude anyone from use (nonexcludability) and where many parties can use the resource simultaneously (nonrivalrous).

The historical commons was often protected, at least for a time, by social rules that limited how many cattle a herdsman could graze. Avoiding a tragedy of the commons with the environment will require its own set of rules which limit how the common resource can be used.

Knowledge and information often display the two key characteristics of a public good. Thomas Jefferson expressed the notion that ideas are at least nonrivalrous and perhaps nonexcludable as well, in elegant language: "If nature has made any one thing less susceptible than all others of exclusive property, it is the action of the thinking power called an idea. . . . No one possesses the less, because every other possess the whole of it. He, who receives an idea from me, receives instruction himself without lessening mine; as he who lights his taper [that is, his candle] at mine, receives light without darkening me."

Ideas discovered as a result of basic scientific research are certainly nonrivalrous; when Percival uses these ideas, it does not reduce Polly's use of them. Ideas stemming from basic research are also nonexcludable, at least to some extent, because once they are known, then understanding of the scientific situation is altered. A knowledge-based public good for which economists have a particular warm spot in their hearts is the collection and publication of economic statistics. Again, this information is nonrivalrous: Quentin's knowing the rate at which the economy has grown doesn't prevent Quintessa from knowing the same information. Such knowledge is also nonexcludable in the sense that once the information is out there—perhaps in a news report—about how the economy is growing, it would be very difficult to prevent that information from spreading.

A number of other government services are referred to as public goods, even if they are not completely nonexcludable and nonrivalrous. For instance, fire and police protection are not easily excludable. It wouldn't be easy to provide fire and police service so that some people in a neighborhood would be protected from the burning and burglary of their property, while others would not be protected at all. Protecting some necessarily means protecting others, too. Police and fire protection are also in some ways nonrivalrous; Oliver's protection from crime or fire doesn't mean that Oleanna is less protected (except perhaps in the extreme case where all the fire or police personnel are busy in one area and can't respond anywhere else).

The Free Rider Problem

Competitive markets made up of a number of different firms and buyers may find it difficult to produce public goods. If a good or service is nonexcludable, like national defense, so that it is impossible or very costly to exclude people from using this good or service, then how can a firm charge people for it? If a good is nonrivalrous, then there is zero marginal cost to adding an additional user, a fact that seems to imply that if businesses compete against each other, the price will keep dropping all the way down to zero. But if businesses can't earn much or any revenue by selling a product, then they will lack an incentive to provide such a good.

When individuals make decisions about buying a public good, a **free rider** problem can arise, in which people have an incentive to let others pay for the public good and then to "free ride" on the purchases of others. The free rider problem can be expressed in terms of the prisoner's dilemma game, which we first discussed as a representation of oligopoly in Chapter 12.

free rider: Those who want others to pay for the public good and then plan to use the good themselves; if many people act as free riders, the public good may never be provided.

Say that two people are thinking about contributing to a public good: Rachel and Samuel. When either of them contributes to a public good such as a local fire department, their personal cost of doing so is 4 and the social benefit of that person's contribution is 6. Thus, the investment is a good idea for society as a whole. But the problem is that while Rachel and Samuel pay for the entire cost of their contribution to the public good, they receive only half of the benefit, because the benefit of the public good is divided equally among the members of society. This sets up the prisoner's dilemma illustrated in Exhibit 15-6.

If neither Rachel nor Samuel contributes to the public good, then there are no costs and no benefits of the public good. If one person contributes and the other does not, then the contributor pays 4 but receives benefits of 3 (that is, half of 6), while the noncontributing free rider also receives benefits of 3. Finally, if both parties contribute, then the total social contribution to the public good is 8 and the total payoff is 12, so each individual has a payoff of 2.

The difficulty with the prisoner's dilemma arises as each person thinks through his or her strategic choices. Rachel reasons in this way: If Samuel does not contribute, then I would be a fool to contribute. However, if Samuel does contribute, then I can come out ahead by not contributing. Both ways, I should choose not to contribute, and instead hope that I can be a free rider who uses the public good paid for by Samuel. Samuel reasons the same way about Rachel. But when both people reason in that way, the public good never gets built, and there is no movement to the option where everyone cooperates that is actually best for all parties.

The free rider problem becomes greater if the concept of the prisoner's dilemma is expanded to include many people, not just two of them. For example, say that 10,000 people are asked to pay $100 in taxes a piece to finance a new road. Each person

Exhibit 15-6
Contributing to a Public Good as a Prisoner's Dilemma

Rachel \ Samuel	Contribute	Don't Contribute
Contribute	A pays 4, gets 6, +2 B pays 4, gets 6, +2	A pays 4, gets 3, –1 B pays 0, gets 3, +3
Don't Contribute	A pays 0, gets 3, +3 B pays 4, gets 3, –1	A pays 0, gets 0 B pays 0, gets 0

will reason as follows: This new road costs me personally $100, but the actual benefits from my $100 are divided by all 10,000 people, so my personal $100 only brings me 1 cent (that is, $100 divided by 10,000) in benefits. If I act as a free rider and refuse to contribute to the road, the road will still be built, I can still drive on the road (because it is nonexcludable and nonrivalrous), and I can save my $100 for something I want to buy for myself. But if everyone reasons this way and acts as a free rider, then no money is collected and the road never gets built.

The Role of Government in Paying for Public Goods

The key insight in paying for public goods is to find a way of assuring that everyone will make a contribution. There must be a way of preventing too many free riders. For example, if people come together through the political process and agree to pay taxes and make group decisions about the quantity of public goods, they can defeat the free rider problem by requiring through the law that people contribute to public goods. Or some roads can be become toll roads, which means that they can now exclude any users who do not pay to drive on them.

However, government purchases and charges are not the only way to provide public goods. Markets can in some cases produce public goods. For example, think about radio. It is nonexcludable, since once the radio signal is being broadcast it would be highly difficult to stop someone from receiving it. It is nonrivalrous, since one person listening to the signal does not prevent others from listening as well. Because of these features, it is practically impossible to charge listeners directly for listening to radio broadcasts. However, radio has found a way to collect revenue by selling advertising, which is an indirect way of "charging" listeners by taking up some of their time. Some public goods will also have a mixture of public provision at no charge along with fees for some purposes, like a public city park that is free to use, but where the government charges a fee for parking your car, for reserving certain picnic grounds, and for food sold at a refreshment stand.

In other cases, social pressures and personal appeals can be used, rather than the force of law, to reduce the number of free riders and to collect resources for the public good. For example, neighbors sometimes form an association to carry out beautification projects or to patrol their area after dark to discourage crime. In low-income countries, farmers in a region may come together to work on a large irrigation project that will benefit all of the fields, and where social pressure strongly encourages all farmers to participate. Many fundraising efforts, including raising money for local charities and for the endowments of colleges and universities, also can be viewed as an attempt to use social pressure to discourage free riding and to serve the outcome that will produce a public benefit.

Positive Externalities and Public Goods

Positive externalities and public goods are closely related concepts. Patents, which are a way of addressing positive externalities, can also be described as an attempt to make new inventions into private goods, which are excludable and rivalrous, so that no one but the inventor is allowed to use them during the length of the patent. For both positive externalities and public goods, one of the possible solutions is to have government spend money directly; that is, direct government spending on research and development or on public goods like national defense. The issue of support for basic research can be discussed both with either the vocabulary of positive externalities (large spillovers) or of public goods (nonexcludable and nonrivalrous).

With regard to both positive externalities and public goods, private firms or individuals acting may fail to make an expenditure or investment that would produce broad social benefits, because the private benefits of such expenditure will be substantially less than the social benefits. In such cases, the challenge for society is to assure that such socially beneficial expenditures are made, whether through direct government spending or by providing appropriate incentives for individuals and firms.

Key Concepts and Summary

1. The pressure of market competition can provide producers with incentives to develop and distribute new technologies. However, if new inventions can easily be copied by others, then the original inventor may not be able to earn a high-than-usual rate of return, in which case innovators would have a reduced incentive to invest in new technologies.

2. New technology often has positive externalities; that is, there are often spillovers from the invention of new technology that benefit firms other than the inventor. The social benefit of an invention, once these spillovers are taken into account, typically exceeds the private benefit to the inventor. If inventors could receive a greater share of the broader social benefits for their behavior, they would have a greater incentive to seek out new inventions.

3. Government has a variety of policy tools for increasing the rate of return for new technology and encouraging its development: direct government funding of R&D; tax incentives for R&D; protection of **intellectual property;** letting companies work jointly on R&D; and helping to finance the spread of available technology.

4. Public policy with regard to technology must often strike a balance. For example, patents provide an incentive for inventors, but they should be limited to genuinely new inventions and not extend forever. Government spending on R&D must be balanced against other government spending priorities.

5. A **public good** has two key characteristics: it is also **nonexcludable** and **nonrivalrous.** Nonexcludable means that it is costly or impossible for one user to exclude others from using the good. Nonrivalrous means that when one person uses the good, it does not prevent others from using it.

6. Markets often have a difficult time producing public goods because **free riders** will attempt to use the public good without making a contribution to paying for it. The free rider problem can be overcome through measures to assure that users of the public good pay for it. Such measures include government actions, social pressures, and specific situations where markets have discovered a way to collect payments.

Review Questions

1. Explain how competition in markets can often provide incentives for the invention of new technology.
2. Using the ideas of social benefit and private benefit, explain the concept of a positive externality.
3. Why does new technology have positive externalities?
4. Why might a competitive market tend to provide too few incentives for the development of new technology?
5. What can government do to encourage the development of new technology?
6. What are the two key characteristics of public goods?
7. Name two public goods, and explain why they are public goods.
8. What is a free rider problem?
9. How can the free rider problem be overcome?