politicians. Since 1933 in the United States, Technocracy, Inc. has been the principal research and educational organization representing the technocracy movement. Its predecessor, the Technical Alliance, was founded in 1919 by Howard Scott (1890–1970), who had been inspired by the writings of Thorstein Veblen (1857–1929). The official publication of Technocracy, Inc. is *North American Technocrat.* Henry Elsner Jr. (1967) has traced much of the history of the technocratic movement in the United States.

SEE ALSO *Bureaucrat; Democracy; Technocracy; Technology*

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TECHNOLOGICAL CHANGE

SEE *Change, Technological.*

TECHNOLOGICAL DETERMINISM

SEE *Determinism, Technological.*

TECHNOLOGICAL DIFFUSION CURVE

SEE *Technology, Adoption of.*

TECHNOLOGICAL PROGRESS, ECONOMIC GROWTH

Technological progress is the fundamental force underlying the long run rise in real income per person. Technological progress reflects the growth of human knowledge, from advances in basic science such as the discovery of the laws of thermodynamics to highly practical and applicable ideas regarding production, like the design of an airplane wing or the mechanization of repeated actions or management and workplace organization, like double-entry accounting, just-in-time production, and the techniques of modern inventory management. It is nearly impossible to overstate the role of technology in economic life. Imagine, for example, how one's life would be different without such everyday inventions as computers and telephones, anesthesia and antibiotics, automobiles and airplanes, and electricity and petrochemicals.

Economic growth occurs because individuals have either more resources at their disposal or better ideas for turning resources into goods and services. Increases in resources alone cannot drive persistent economic growth. Natural resources are limited in a finite world, and while education can dramatically increase the productivity of human resources, such gains are constrained by human lifespans. Countries have doubled the education of their workforce, going from five years of schooling to ten, but it is hard to imagine repeating this accomplishment. The gains available from mechanization are also limited. If industry increases the number of machines per worker, growth will slow as each machine adds less to output than the one before. Indeed, estimates pioneered by Nobel laureate Robert Solow attribute less than half of U.S. economic growth to increases in resources. The lion's share of growth stems from technical progress.

In addition to playing a central role in persistently rising income levels, the advance of scientific and technical knowledge have driven a number of important economic trends. In production, technological progress has been the primary force underlying the shifts from manual to mechanized production methods, from natural to synthetic materials, from human and animal to mineral sources of power, and from raw labor to highly educated and specialized workers. The adoption of new technologies often drives the expansion of markets. Larger markets are required to allow workers and firms to concentrate on highly specialized activities and increase the return to innovations that involve investments in specialized knowledge or machinery. Innovations in transportation and communication have induced correspondingly dramatic changes in the organization of economic activity, shifting production out of the home, raising the average size of business enterprises, concentrating production in cities, and increasing the geographic extent of trade and the role of international transactions in local and national economies.

SOURCES OF TECHNOLOGICAL PROGRESS

The Industrial Revolution, which marks the beginning of a unique economic era of persistent increases in per capita incomes, is inextricably linked to the scientific revolution, and the world's current economic prosperity is difficult to imagine in the absence of fundamental advances in knowledge of biology, physics, and chemistry. Not all new technologies come from the scientific community, however. Private firms devote tremendous resources to applied research and development. In addition, many economically valuable ideas are the result of practical experimentation and the gradual accumulation of production experience. Even such high profile "inventions" as the Fulton steam engine—the mobile power source of the Industrial Revolution—drew on more than one hundred years of incremental improvements on earlier designs.

Unlike a hammer or a tractor, an idea can be used by many people at the same time. Indeed, because commercial success tends to attract attention, good ideas usually are hard to conceal. Once Henry Ford demonstrated that inexpensive cars could be mass produced on assembly lines, his production methods were widely copied. While early gains from an idea go to the inventor, as an idea spreads throughout an industry competitive pressure drives down prices, creating gains for society at large. Indeed, attempts to make use of the constant stream of new ideas generated by their competitors plays an important role in the tendency of firms in a given industry to locate close to each other, forming industrial clusters like Silicone Valley, Wall Street, and Hollywood.

Scientific research often generates insights that are valuable in many lines of business. Because of this, basic research is supported with public funds and new discoveries are widely disseminated. In more narrow and applied areas of knowledge, research is supported through the protection of intellectual property rights. These grant inventors a temporary monopoly on the use of their ideas, allowing them to recoup their research expenditures. Intellectual property rights attempt to balance the desire to reward successful research with the social benefits that derive from competitive markets and the widespread adoption of good ideas. In the pharmaceutical industry, drug prices typically fall by around 80 percent when a patent expires.

In addition to intellectual property rights, an educated workforce is essential to successful public and private research. Perhaps less obvious is the role of international trade. Access to large markets allows firms to spread the fixed cost of inventing a new idea thinly over a large number of units of output, raising the return to resources devoted to research. It is probably no accident that at the time of its Industrial Revolution, England had both the only European system of intellectual property rights and, due to an extensive network of roadways and canals, the most integrated national market in Europe.

INTERNATIONAL TECHNOLOGICAL TRANSFERS AND ECONOMIC DEVELOPMENT

For countries that are not on the technological frontier, technological progress owes more to imitation than innovation. Late industrializers—from the United States in the nineteenth century to China and India in the twenty-first—have always borrowed from the technological leaders of their day. The persistence of dramatic international disparities in income levels, however, testifies to the fact that successfully adopting existing technologies is neither easy nor automatic. Many technologies need to be adapted to fit local conditions including labor force skills, regulatory environment, availability of vital resources, and cultural differences.

Openness to international markets and an efficient legal system that protects the rights of foreign investors play important roles in attracting multinational companies that employ advanced technologies. Many developing countries, including China and India, have seen a marked increase in their growth rates directly following opening to international trade and foreign investment. On the other hand, international trade may lead developing countries to specialize in less technologically dynamic economic activities, such as agriculture and mining, and foreign investment in these areas may do little to promote ongoing technological transfers.

Because the introduction of a new technology generally creates both winners and losers, international technology transfers may also face deliberate and well-organized opposition. New technologies are often opposed by preindustrial elites that fear the loss of leadership to a new industrial class, by existing industries that are invested in older technologies, and by labor unions who fear the loss of jobs.

MANAGING THE CHALLENGES OF TECHNOLOGICAL PROGRESS

While technological progress raises average incomes over the long run, the costs and benefits of new technology are generally unevenly spread, creating a number of challenges for countries experiencing rapid technological progress. The introduction of new goods and processes often competes directly with established economic firms, causing them to adapt or be driven out of business, a process termed *creative destruction* by economist Joseph Schumpeter. The rise of the personal computer in the

1980s provoked a serious crisis at IBM, the leading maker of mainframe computers.

Technologies that raise output per worker are labor-saving by definition. Since the end of the Civil War (1861–1865), ongoing technical progress has reduced the share of agriculture in U.S. employment from 50 percent to less than 2 percent, and a similar process is currently underway in manufacturing. This release of labor from agriculture to other sectors has been an important force in rising U.S. living standards, but these large sectoral shifts have been a painful process for those directly involved.

Because the costs and gains from technical progress are unevenly shared, periods of rapid technical progress often see dramatic increases in income inequality such as characterized the European countries during their Industrial Revolutions. Because they were better able to adapt to the challenges of the computer revolution, educated workers have seen their wages rise quickly while other workers' wages have stagnated.

In addition to managing the labor market turbulence and larger sectoral shifts brought about by technological progress, technologically dynamic economies may face a host of unanticipated challenges that call for innovative economic, legal, and regulatory responses. The spread of the automobile gave rise to the suburbs and fundamentally altered American cities. The development of household appliances reduced the time required for routine housework, contributing to the rise in female labor force participation and changes in family structure. Advances in information technology may require new regulatory and legal responses to protect intellectual property rights in media, deter identity theft, and cope with the challenges of increased global competition.

These are nontrivial challenges, but technological progress has also provided the world with a greater capacity to meet them. Industrialization has provided both industrial pollution and the means to manage it, and the economic surplus created by increasing output per person has provided management with the ability to support and retrain workers who lose their jobs to technical progress. As in the realm of technology itself, the ability to meet the challenges raised by ongoing technological progress is limited ultimately by human creativity itself.

SEE ALSO *Business Cycles, Real; Change, Technological; Research and Development; Technological Progress, Skill Bias; Technology; Technology, Adoption of; Technology, Transfer of*

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TECHNOLOGICAL PROGRESS, SKILL BIAS

This entry will discuss the different approaches to total factor productivity measurement and define skill-biased technical change. Let t denote a technology index and x and y denote inputs and output, respectively. Then the production function can be written as

$$y = f(x, t).$$

Technological change is then defined as a change in the technology index t that affects the relationship between inputs x and output y. Given a change in t (say from t_1 to t_2), technological change is said to take place if

$$\frac{\partial f(x,t)}{\partial t} \neq 0.$$

Assuming that $t_2 > t_1$, technological change is called *technological progress* if

$$\frac{\partial f(x,t)}{\partial t} > 0,$$

that is, if technological change allows the production of more output y with the same quantity of inputs x. Alternatively, technological change is called *technological regress* if

$$\frac{\partial f(x,t)}{\partial t} < 0.$$

Technological progress is usually measured in terms of the *rate of technological progress*

$$\frac{\partial \ln f(x,t)}{\partial t}. \qquad (1)$$

Under the assumption of constant returns to scale (which is the maintained assumption in this article), the rate of technological progress is also referred to as the *growth rate of total factor productivity* (TFP) or *total factor productivity growth.*