Elements of Innovation Systems 3

Innovation rarely results from the actions of a single individual or firm; rather, it is the result of numerous interactions by a community of actors that is often widely dispersed both geographically and temporally. Scientists discover new facts and develop new theories about the workings of nature; engineers design and develop new technologies and products; financiers—both public and private—fund research, development, and manufacturing; skilled laborers manufacture new products and implement new processes; and public and private institutions educate and train these different types of workers. This community often extends beyond the boundaries of any particular firm or nation. For example, continued development of high-temperature superconductivity, though discovered by IBM researchers in Switzerland, will depend on scientific and technological advances in the United States, Japan, and Europe. It will also depend on the availability of financing—whether public or private—in each of these nations and regions.

Although influenced by the strength of the international community as a whole, the ability of any particular nation to capitalize on new technological developments depends heavily on its system of innovation. Nations vary considerably in the ways innovation occurs within their borders and in the relationships among industry, government, and academia.[1] In Japan and Europe, industry and government are more closely linked than in the United States, and universities play a smaller role in industrial research. Japanese corporations also have a stronger history of collaboration than U.S. firms, due in part to encouragement by their government. Differences in the structure of national innovation systems are partially responsible for differences in competitive performance.

Because of the myriad factors influencing innovation, policymakers interested in facilitating the commercialization of emerging technologies must consider not only the means by which firms develop particular products, processes, or services, but also the need for creating and supporting the necessary institutions and institutional relationships. While many innovations are largely compatible with existing infrastructure, radical innovations often require an entirely new set of relationships and institutions. The required infrastructure consists of nine basic elements that can

[1] For an international comparison of innovation systems, see Richard R. Nelson (ed.), *National Innovation Systems: A Comparative Analysis* (New York, NY: Oxford University Press, 1993).

TABLE 3-1: Generic Components of Industry Infrastructure for Innovation

Institutional arrangements
Governance (norms, rules, regulations, laws)
Legitimation (creation of trust)
Technology standards
Resource endowments
Scientific/technological research
Financing and insurance arrangements
Human resources
Proprietary functions
Technology/product development
Networking and development of vendor/distributor channels
Market creation and consumer demand

SOURCE Andrew H Van de Ven, "A Community Perspective on the Emergence of Innovations, " *Journal of Engineering and Technology Management,* vol. 10, No 1, June 1993, p 26

be grouped into three general categories (see table 3-1).[2] The lack of any one of these elements can cripple attempts to innovate and launch new industries. While creation of these elements is the task primarily of the private sector in the United States, government either directly or indirectly influences aspects of nearly all of them.

This chapter analyzes the nine elements of innovation systems to demonstrate their significance in the innovation process and to highlight the contribution of government to each. As shown through both historical and contemporary examples, industry and government have forged a complex set of relationships in different industries to support the tasks of innovation and commercialization. Government influences both the development of new technology and the creation of markets by funding research and development (R&D); procuring goods and services for public missions; providing regulatory approvals; helping set technical standards; issuing regulations on human health and the environment; sponsoring technology demonstrations; and enforcing tax, antitrust, and patent laws. Government contributes to innovation and commercialization by: being an early or important user; providing information that informs the decisions of the private sector; and supporting private-sector efforts, rather than dictating how they should proceed.

As industries develop, firms determine which parts of the infrastructure they will develop: 1) individually, 2) in collaboration with other firms, and 3) with the support of government. The resulting linkages are often numerous and overlapping, and change over time as the industry evolves.

GOVERNANCE

Government rules, regulations, and laws affect the ability of firms to innovate, and can either facilitate or inhibit the emergence of new industries. Particular aspects of governance affecting innovation include patent policy, antitrust provisions, and regulations in areas such as environmental protection and human health. Patent policy, for example, gives firms an incentive to innovate by granting them exclusive rights to their inventions and by protecting these rights against infringe-

[2] This framework derives from the work of Andrew H. Van de Ven, "A Community Perspective on the Emergence of Innovations," *Journal of Engineering and Technology Management,* vol. 10, 1993, pp. 23-51; and Andrew H. Van de Ven and Raghu Garud, "A Framework for Understanding the Emergence of New Industries,"in *Research on Technological Innovation, Management, and Policy,* vol. 4, Richard S. Rosenbloom (cd.) (Greenwich, CT: JAI Press Inc., 1989), pp. 195-225.

ment. By requiring public disclosure of new inventions, the patent process also encourages dissemination of new technical information. Changes in enforcement of patent law also influence the ability of firms to innovate. Commercialization of microelectronics and biotechnology was aided, in part, by a permissive patenting regime that reduced the threat of litigation against newer firms that adapted innovations originally developed within established firms or research institutions.[3]

Similarly, antitrust law governs the types of activities, such as research or production, that firms may jointly undertake in developing new technologies. U.S. antitrust provisions are generally more stringent than those of the nation's primary industrial competitors. Strict enforcement of antitrust provisions in the postwar era has been cited as one of the factors that led to the creation of large integrated research firms in the United States.[4] Conversely, investigations of alleged antitrust activities by two of the largest electronics corporations, AT&T and IBM, ended in consent decrees (both issued in 1956) that required widespread licensing of inventions in microelectronics and computers, respectively, fostering competition and aiding entry by new firms. Clarifications of antitrust law have also served to encourage innovation. The National Cooperative Research and Development Act of 1984 allows companies to collaborate on R&D—through the prototype stage—without being presumed to violate antitrust laws, and, in some cases, removes the treble damages penalty against firms found in violation of the law. The 1984 act had a liberating effect on consortia, encouraging several hundred to form within the first few years. As amended in 1993, the act now extends such protections to firms collaborating in production as well as R&D.

LEGITIMATION

Legitimation is the attempt to reduce customer uncertainty about new products, processes, and services in order to promote development of new markets. Lack of trust can be a significant barrier to the successful commercialization of innovations that are costly, technologically sophisticated, or potentially harmful to human health and the environment. With emerging technologies, in particular, performance often is difficult to guarantee because the properties of the technology are not fully understood, the underlying science is not yet fully developed, and the functioning has not been fully tested during years of use and modification. Risks and costs are difficult to quantify, and the objectivity of information provided by the producer is suspect.

Both the private and public sectors play a role in legitimizing new technologies. Private organizations such as the Consumers' Union provide independent evaluations of consumer products, engineering consultants help evaluate and approve larger scale projects, and private standards organizations may certify performance of equipment. In the public realm, policies governing product liability suits and the size of possible awards (compensatory and punitive) affect the incentives for companies to thoroughly test their products and seek approvals. The threat of medical malpractice suits, for instance, is an incentive for practitioners to adopt medical services and devices that they might not otherwise use if only price and performance were considered.[5] Government approval of new technologies can help reduce customer uncertainty. Many regulatory approval programs in the Food and Drug Administration (FDA) and the Federal Aviation Administration (FAA) play this role by enforcing

[3] David Mowery and Nathan Rosenberg, "The U.S. National Innovation System," in *National Innovation Systems*, Richard Nelson (ed.) (New York, NY: Oxford University Press, 1993), p. 49.

[4] Ibid.

[5] Annetine Gelijns and Nathan Rosenberg, "The Dynamics of Technological Change in Medicine," *Health Affairs*, summer 1994, p. 29.

standards for safety. Government-sponsored demonstrations of new technology also can provide potential customers with valuable information on which to base purchasing decisions.

Regulatory Approvals

Regulatory approvals are an inherent part of the commercialization process for many innovations in pharmaceuticals, aerospace, and other industries. Approvals help ensure the safety of innovations that, through their manufacture or use, could adversely affect human health and the environment. Failures can be costly for customers; damages can far exceed the cost of the product itself. Unsafe drugs can have health effects far more severe than the conditions they are supposed to ameliorate, and failed aircraft engines can result in the loss of the aircraft, passengers, and cargo.[6]

The lack of an effective regulatory approval process can be debilitating to sales of such products because consumers often have limited alternatives for independently evaluating safety and efficacy on their own. Moreover, lack of an appropriate regulatory structure can prevent emerging technologies from being evaluated on their own merits. Commercialization of cochlear implants for the hearing impaired, for example, was aided by the formation of a separate panel within the FDA to evaluate cochlear devices on terms and standards more appropriate to the technology than those developed for existing alternatives, such as vibrotactile and hearing aid devices. The establishment of a special committee within the American Speech and Hearing Association to evaluate safety and efficacy of cochlear implants helped further distance the new technology from the old.[7]

Clearly, regulatory approvals can burden innovators by adding time and uncertainty to the commercialization process. Biotechnology companies view the FDA requirement that companies simultaneously submit applications for both drugs[8] (Product License Applications) and their manufacturing facility (Establishment License Applications) as particularly burdensome because they require the firm to invest in full-scale production facilities before knowing whether the drug will be approved. Biotechnology industry executives also complain about unclear FDA review requirements and inadequate communications between the agency and industry.[9] Tensions exist between the desire to rapidly bring new products to market, and the need to protect the public from potentially deleterious effects of new technologies. While weaker approval standards for medical products and pesticides could speed commercialization, they could also come at the cost of human health and undermine consumer confidence, thereby slowing adoption and diffusion. Looser permitting requirements could allow industry to install new process technologies more quickly, but might create loopholes that allow firms to pollute the environment more and endanger the safety of workers and nearby communities.

Increased cooperation among federal, state, and local regulatory agencies may make regulatory approvals more conducive to innovation without compromising health, safety, and the environment. Such actions could broaden markets by lowering the expenses and uncertainties innovators and their potential customers face when implementing new technologies in different jurisdictions. Unlike national regulatory approvals granted in the pharmaceutical and aerospace industries, regulators in environmental and other areas usually have separate procedures and requirements for permitting new facilities in differ-

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[6] Such high costs are one of the reasons the aircraft industry, in particular, is often slow to adopt radically new technologies that have not been rigorously analyzed and tested.

[7] See Van de Ven and Garud, op. cit., footnote 2, p. 204.

[8] Actually biologics in this case. Biologics, which include vaccines, blood products, and other products derived from living tissues, are regulated somewhat differently from drugs made through chemical synthesis.

[9] Kenneth B. Lee, Jr. and G. Steven Burrill, *Biotech 95: Reform, Restructure, Renewal* (Palo Alto, CA: Ernst & Young LLP, 1994), p. 25.

ent states. The Western Governors Association has an initiative under way to encourage states to recognize data submitted to other states for permitting,[10] and California initiated an environmental technology certification program that might give potential customers and regulators confidence in innovative compliance technologies. In the health care industry, too, differing state requirements hamper streamlining of health administration records.[11]

In addition, approval processes can often be streamlined. In 1988, in response to the AIDS epidemic, FDA issued "Subpart E" regulations to expedite approvals for drugs to treat life-threatening and severely debilitating conditions.[12] However, expediting approval for particular types of products may both delay and raise the cost of approvals for other products. In the late 1980's, FDA reviewed some of its drug approval regulations and implemented a number of changes. These changes simplify or reduce some regulatory requirements, increase and improve communications between the agency and applicants, and alter contents and formats on applications to facilitate review, among other actions.[13] Such activities may be continued as other regulations are due to be rewritten. FDA has also proposed streamlining approvals for certain drugs and devices. This proposal includes a pilot program to allow manufacturers to hire private reviewers for certain devices, although final approval would still be given by the FDA.[14,15] Computerization of applications, data submittal, and regulatory review—as well as better training of regulatory agency reviewers—may also help speed the approval process for FDA, the Environmental Protection Agency (EPA), and other agencies.

Technology Demonstration and Performance Verification

Testing, evaluation, and demonstration outside of the regulatory context provide an alternative means of building consumer confidence in new products, processes, and services. Developers commonly build prototypes, bench-scale models, and pilot plant facilities before adopting new technologies or offering them in the marketplace. Firms also test-market new offerings before committing to full-scale production, or seek certification from private standards organizations. For pharmaceuticals, demonstration of efficacy and safety is a condition for regulatory approval. Collective industry action—coordinated through industry councils, technical committees, and trade associations—can assist in the promulgation of industry regulations and safety standards, and can help overcome concerns about the viability of new technology. For instance, SEMATECH—a consortium of 11 large semiconductor manufacturers—tests and qualifies new and improved semiconductor manufacturing equipment.[16] The results are shared with member firms who can use the results in their purchasing decisions; equipment suppliers also use the test results to gain feedback on their products.

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[10] U.S. Environmental Protection Agency, "Technology Innovation Strategy of the U.S. EPA," external discussion draft, Washington, DC, January 1994.

[11] See U.S. Congress, Office of Technology Assessment, *Bringing Health Care Online: The Role of Information Technologies,* OTA-ITC-624 (Washington, DC: U.S. Government Printing Office, September 1995), ch. 3.

[12] U.S. Congress, Office of Technology Assessment, *Pharmaceutical R&D: Costs, Risks and Rewards*, OTA-H-522 (Washington, DC: U.S. Government Printing Office, February 1993), p. 155.

[13] Ibid., pp. 151-158.

[14] Philip J. Hilts, "F.D.A. Moves To Hasten Marketing of New Devices," *New York Times*, Apr. 7, 1995, p. A22.

[15] "FDA Plans To Speed Approvals," *Financial Times*, Mar. 17, 1995, p. 6.

[16] Peter Grindley, David C. Mowery, and Brian Silverman, "SEMATECH and Collaborative Research: Lessons in the Design of High-Technology Consortia," *Journal of Policy Analysis*, vol. 13, No. 4, 1994, pp. 723-758.

While demonstrations occur largely in the private sector, government, too, has a useful role to play, especially in providing unbiased information to developers and users (see box 3-1 for a description of government demonstration programs for scalable parallel computers). Government demonstrations and evaluations are often most effective when the government, federal laboratories, and government-supported entities (such as universities) possess specialized or unique facilities or expertise useful for testing and evaluation. For instance, the National Aeronautics and Space Administration's (NASA's) wind tunnels, computational models, and flight-testing capabilities are useful for demonstrating and validating new civil aviation technologies.[17]

Government capabilities are also useful in evaluating technologies developed to meet regulatory requirements. For example, the Superfund Innovative Technology Evaluation (SITE) program, sponsored by EPA, helps speed the development and diffusion of new environmental remediation technologies by allowing vendors to test new technologies at contaminated sites.[18] A number of federal, state, and university-associated facilities also provide some testing and evaluation services for environmental technologies, although difficulties and uncertainties in permitting fixed test facilities and onsite demonstrations limit their effectiveness.[19] The largest federally supported demonstration program is the Clean Coal Technology Demonstration Program (CCT), which received $2.4 billion from the Department of Energy (DOE) and $4.6 billion in nonfederal contributions.[20] Because many CCT projects are still under way, it is too early to ascertain the final results of the program. However, a number of commercial sales of clean coal technologies have followed the demonstration.

Federal support of technology demonstrations appears to yield poor commercial dividends if: 1) demonstrations are conducted before major research uncertainties are resolved, 2) government technology push overwhelms market pull, or 3) there is low industry commitment to demonstration through cost-sharing. Government-supported development and demonstration of ceramic engine components, the supersonic transport (SST), the space shuttle, synthetic fuels, the Clinch River breeder reactor, and a variety of renewable energy projects have failed largely for these reasons.[21] In a number of these cases, the federal government continued to fund projects even as technical and economic milestones were not achieved, cost overruns accrued, and industry support weakened. To ensure greater success, government must win strong industry interest and financial commitment, avoid hasty leaps toward demonstration when important research problems remain unresolved, and maintain managerial and political dis-

[17] National Research Council, *The Competitive Status of the U.S. Civil Aviation Manufacturing Industry: A Study of the Influences of Technology in Determining Competitive Advantage* (Washington, DC: National Academy Press, 1985), cited in John A. Alic et al., *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston, MA: Harvard Business School Press, 1992), p. 403, fn. 20.

[18] U.S. Environmental Protection Agency, "Innovative Hazardous Waste Treatment Technologies: A Developer's Guide to Support Services," 2nd edition, EPA 540/2-91/012, June 1992. SITE's 1995 budget was $16 million; EPA evaluation programs for waste reduction and municipal waste technology evaluation were much smaller; see U.S. Congress, Office of Technology Assessment, *Industry, Technology, and the Environment: Competitive Challenges and Business Opportunities*, OTA-ISC-586 (Washington, DC: U.S. Government Printing Office, January 1994).

[19] U.S. Environmental Protection Agency, National Advisory Council for Environmental Policy and Technology, *Report and Recommendations of the Technology Innovation and Economics Committee: Permitting and Compliance Policy: Barriers to U.S. Environmental Technology Innovation*, EPA 101/N-91/001, January 1991; U.S. Congress, Office of Technology Assessment, ibid.

[20] U.S. Department of Energy, *Clean Coal Technology Demonstration Program: Program Update 1993*, DOE/FE-0299P, March 1994.

[21] U.S. Congress, Office of Technology Assessment, *Commercializing High-Temperature Superconductivity*, OTA-ITE-388 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 44-45; Linda R. Cohen and Roger G. Noll, *The Technology Pork Barrel* (Washington, DC: The Brookings Institution, 1991); Alic et al., op. cit., footnote 17, pp. 369-370.

BOX 3-1: Evaluation and Demonstration of Scalable Parallel Computers

Scalable parallel computers (defined in box 1-3) can sometimes provide the performance of a conventional supercomputer at a much lower price. Many designs of scalable parallel computers compete in the market, and potential users often have difficulty determining which design best suits their particular needs, Because the machines are still quite expensive and writing software for them is difficult, users incur substantial costs if they buy machines just to try them out or make an incorrect choice in their purchase. The limited penetration of scalable parallel computers into the marketplace limits the ability of potential buyers to learn from other users about the strengths and weaknesses of particular designs in different applications.

As a large user of high performance computing, the federal government has long been interested in evaluating supercomputer performance and learning to use supercomputers efficiently. Through its own efforts, the government has been in a good position to help inform other potential users.

One example is benchmarking, which is measuring the speed with which computers perform certain standard calculations. These benchmark calculations are not whole applications programs, rather, they are one or more isolated calculations (such as matrix inversion) chosen to represent the types of computation the user expects to encounter. Different benchmark tests involve calculations typical of different types of applications. Researchers at the Department of Energy's Oak Ridge National Laboratory (ORNL) first conducted benchmark evaluations m 1979. Since then, researchers at ORNL and at the National Aeronautics and Space Administration's (NASA's) Ames Laboratory have run a variety of benchmark tests on a range of different supercomputers and made the results available to industry. The benchmark reports have helped potential users, many of whom have difficulty evaluating manufacturers' performance claims. [1] Government benchmark results do not usually provide enough information to make a purchasing decision, but they help in choosing machines for further evaluation, The results also provide valuable feedback to manufacturers.

The Joint National Science Foundation (NSF) -NASA Initiative on Evaluation (JNNIE) is studying the performance of numerous scalable parallel computers on a wide variety of computations. As well as measuring performance, the project seeks to understand why the machines perform as they do, including the effect of different computer design features. The project will also evaluate the ease of use of different machines. This project could provide valuable information to users as well as to manufacturers designing next-generation computers.

The federal government has also made it easier for firms to try out these computers for themselves. NSF funds a high performance computing Metacenter, which includes five national computation laboratories the Cornell Theory Center, the National Center for Atmospheric Research, the University of Illinois' National Center for Supercomputing Applications, the Pittsburgh Supercomputing Center, and the San Diego Supercomputer Center. While these labs primarily serve government and academic missions, in some cases, firms have used the labs' computers, software packages, and consulting services for their own purposes. Private firms must pay the centers for work that is kept proprietary, for results that become publicly available, grants are available on a competitive basis to defray costs. In 1994, to increase access to industry and academia, NSF expanded its Metacenter to include six Regional Alliances,[2]

SOURCE: Office of Technology Assessment, 1995.

[1] D. Bailey "Twelve Ways To Fool the Masses When Giving Performance Results on Parallel Computers," *Supercomputing Revlew,* August 1991, pp. 54-55

[2] "NSF Establishes Six Supercomputing Subcenters with $6 Million in Awards, " *High Performance Computing and Communications Week,* vol. 3, No 44, Nov. 10, 1994, p. 3.

cipline to terminate programs when project failure is apparent.

TECHNOLOGY STANDARDS

Standards are defined as acknowledged measures of comparison for quantitative or qualitative values, or norms.[22] Thus, standards can be virtually any characteristic by which a class of objects is compared. For example, pistols can be compared by the size of bullet they use; and automobiles can be compared by how many miles they can travel per gallon of fuel. The term *standard* can refer to both the characteristic being measured (bullet size or miles per gallon) and to a specific required value for that characteristic (0.22 caliber, 30 miles per gallon).

Technical standards are particularly important in the development of new technologies because they help channel resources toward a limited number of designs. Standards also provide a basis for products to interact compatibly. For example, two fax machines that use the same standard for encoding transmitted data can communicate with each other, even if they work very differently internally. Similarly, a touch typist trained on one typewriter can readily switch to another one because virtually all English-language typewriters in use today arrange the letters in a standard pattern, starting with QWERTY at the left side of the upper row.

Standards can be established in several ways. Industry may agree on standards; government may impose them; or the market may determine them. Often a standard is established by the dominant producer of a new technology, but such de facto standards can take considerable time to emerge if several competitors offer different designs. Major consumers can also create de facto standards, as in the case of military standards and specifications on certain electronic assemblies. Numerous committees have been established, with and without the help of government, to facilitate standards-setting. While technical considerations are important in standards-setting, social and political considerations often overwhelm them as companies attempt to impose the standards that best suit their own interests.

The governments of Japan and many European countries provide a great deal of support to the private sector's standards activities and view standards as a strategic tool to enhance markets for domestic industries. The U.S. government provides much more modest support and a less strategic view.[23] It has taken an active role in cases in which the government is a large user of a technology, as with software (see box 3-2), or has an accepted regulatory role, as with broadcasting. In high definition television (HDTV), for example, the Federal Communications Commission (FCC) encouraged firms to develop digital—as opposed to analog—systems for transmission and display of HDTV broadcasts. After evaluating four proposed systems—none of which was clearly superior—the federal government encouraged competing teams to arrive at a consensus on a digital standard.[24] The shift to a digital standard may have put U.S. firms back in the running against Japanese firms, which had staked out an early lead in HDTV with its analog MUSE standard. Digital systems offer many performance advantages over analog systems, most notably in signal processing and compression capabilities, and allow greater synergy with U.S. strengths in computer technology. Though Japanese manufacturers will likely be strong competitors in producing devices that meet the U.S. standard, their competitive position will be much weaker than if the United States had adopted the MUSE standard.

Federal procurement policies also influence standards-setting. After several years of debate

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[22] *The American Heritage Dictionary of the English Language*, New College Edition (Boston, MA: Houghton-Mifflin, 1980).

[23] U.S. Congress, Office of Technology Assessment, *Global Standards: Building Blocks for the Future*, TCT-512 (Washington, DC: U.S. Government Printing Office, March 1992), ch. 1, esp. pp. 17-18.

[24] See J. Hart, "The Politics of HDTV in the United States," *Policy Studies Journal*, vol. 22, No. 2, summer 1994, pp. 213-238.

BOX 3-2: Industry/Government Interaction To Develop Standards for Software Portability

Widespread diffusion of computer technology—from desktop PCs to high-performance computers—hinges on the development of standards to promote software portability; that is, the ability of software written for one type of computer to run correctly and efficiently on another type of computer without modification, Portability encourages development of applications software because it expands potential markets to Include owners of different types of computers. Increased software development, in turn, makes the computer hardware more valuable because it can perform more functions.

Government has been involved in several industry efforts to develop standards to promote software portability, including development of the COBOL programming language in the 1960s. Some recent examples include scalable parallel computing, whose commercialization has been hampered by a proliferation of differing computer architectures that run incompatible software. No single architecture has yet become an Industry standard, which has stymied the development of applications software and made the machines less attractive to prospective users.

To help overcome this deficiency, the federal government supported the development of the Message Passing Interface (M PI) standard, which helps to make applications portable across different types of scalable parallel computers. ' The standard defines a set of system software routines that applications programs may call to pass messages between processors. Each participating computer manufacturer provides system software routines written to run efficiently on its machine, taking into account factors such as the number of processors and the number, speed, and arrangement of communications channels between them. When a program is ported (i.e., moved) from one machine to another, the second machine's system software routines perform the required interprocessor communication efficiently, just as the first machine's system software routines had done. This approach, while not perfectly efficient and not always applicable, has substantially contributed to software portability.

The effort to create the MPI standard, lasting from summer of 1991 until March 1994, was led by the University of Tennessee and the Department of Energy's Oak Ridge National Laboratory, and was supported by modest grants from the Advanced Research Projects Agency (Department of Defense) and the National Science Foundation (NSF). Several European participants were supported by ESPRIT, a technology program of the European Union. The process involved two-day working group meetings every six weeks for nine months and extensive discussions by electronic mail, both open to all in the high-performance computing field. Most major vendors of scalable parallel computers participated, and the MPI standard was strongly influenced by existing industry message-passing approaches.[2]

Government is also supporting the High Performance Fortran Forum (HPFF), an ongoing effort led by Rice University and the NSF-supported Center for Research on Parallel Computation. HPFF is trying to extend the standard Fortran computer language to computers having more than one processor. Fortran, commonly used in scientific and engineering computing, was developed to run efficiently on various single processor computers and is not well suited for use on multiprocessor machines. Various extensions of Fortran were developed for particular multiprocessor machines, but a standard, widely accepted extension of Fortran was needed to achieve software portability. HPFF is trying to achieve this. A first version of a standard Fortran extension was completed in the fall of 1994; an improved version is under development. As with the MPI standard, the HPFF's approach is not perfectly efficient, and IS not always applicable; but the HPFF's effort is expected to contribute substantially to software portability.

SOURCE: Office of Technology Assessment, 1995

[1] MPI is intended primarily for distributed memory computers and for networks of workstations, but can also be used for shared memory computers *The Internationai Journal of Supercomputer Applications and High Performance Computing,* vol. 8, Nos. 3/4, fall/winter 1994, pp. 159-416 (Special Issue: MPI: A Message-Passing Interface Standard), p 171

[2] Ibid., pp. 165-168

between IBM and other computer manufacturers (including RCA and Univac) regarding a standard for COBOL, a high-level computer language for business applications, the American National Standards Institute (ANSI) adopted a single standard COBOL version. DOD quickly adopted that standard as a federal data processing standard, guaranteeing that major manufacturers would supply compilers for the ANSI version of COBOL, and enabling programs written in ANSI COBOL to be used on various types of computers.[25]

Federal procurement standards can sometimes impede the commercialization of new technology by being overly prescriptive. Military standards and specifications have been cited as factors that limit innovation in developing systems for the military and that segregate the military and commercial domestic production bases.[26] Military standards and specifications often specify in detail the inputs and processes required in the production of goods and services. As practices have changed in the commercial sector, military standards have presented increasingly insurmountable barriers to commercial firms that might otherwise participate in defense markets. For many advanced technologies, the military's reliance on outdated standards has left it behind commercial systems in performance; this practice has resulted in segregated manufacturing facilities for military systems, driving up the costs of production. Recognizing these problems, DOD has begun to move toward performance-based standards that emphasize characteristics of the end product or system, rather than the method of production. This approach allows military procurement officials to take advantage of the commercial sector in many areas. It also enables the use of military procurement policies in fostering the development of new technologies and products, such as those that are less harmful to the environment (see box 3-3).

Government attempts to dictate standards for commercial or dual-use technologies (i.e., those with both military and commercial applications) have also run into difficulty. DOD's efforts to establish Ada as a standard language for object-oriented computer software, for example, have generally fallen short of their initial objectives and failed to promote synergy between defense and commercial computer markets. Similarly, government adoption of the Escrowed Encryption Standard (EES) in 1994 as a voluntary, federal information-processing standard has not enticed commercial organizations to follow. This standard includes a decrypting key that can be reconstructed by combining information escrowed with two different federal agencies. Only with a court order—and for law enforcement purposes only—would the information from the two agencies be combined to decrypt a particular communication. Because of its interest in law enforcement, the government hoped that EES would be accepted by industry. However, the private sector has shown little interest in EES since it can be cracked by the government.[27]

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[25] IBM apparently opposed the standard proposed by RCA and Univac because easy transfer of software from one machine to another would help RCA and Univac to compete against IBM, which dominated the market. Such behavior by IBM is consistent with economic theory; see S. Besen and J. Farrell, "Choosing How To Compete: Strategies and Tactics in Standardization," *Journal of Economic Perspectives,* vol. 8, No. 2, spring 1994, pp. 126-129.

[26] For an examination of factors in the integration of defense and commercial sectors, see U.S. Congress, Office of Technology Assessment, *Assessing the Potential for Civil-Military Integration: Technologies, Processes, and Practices*, OTA-ISS-611 (Washington, DC: U.S. Government Printing Office, September 1994).

[27] U.S. Congress, Office of Technology Assessment, *Information Security and Privacy in Network Environments*, OTA-TCT-606 (Washington, DC: U.S. Government Printing Office, September 1994), pp. 127-132; see also U.S. Congress, Office of Technology Assessment, *Issue Update on Information Security and Privacy in Network Environments*, OTA-BP-ITC-147 (Washington, DC: U.S. Government Printing Office, June 1995).

BOX 3-3: Military Standards and the Development of CFC Alternatives

Military standards and specifications are important factors that govern the cleaning of electronic assemblies. Because the military is such a large customer for electronic products, its standards have served as de facto Industry standards. One example is CFC-113, a solvent used for cleaning electronic assemblies, fine optical and mechanical parts (e. g., disk drives and gyroscopes), and dry cleaning of delicate materials. CFC-113's superior cleaning characteristics, noncorrosiveness, low cost, low toxicity, slight odor, and nonpolluting qualities made the compound ideal for many cleaning applications. The chemical's characteristics also meant that users did not have to install and operate expensive ventilation or air pollution control equipment. A 1989 estimate suggested that 50 percent of global CFC-113 use in electronic circuit board manufacturing was determined by U.S. military specifications.

However, CFC-113 has been identified as an ozone-depleting substance (ODS). In September 1987, the United States joined 23 other countries in signing the Montreal Protocol on Substances that Deplete the Ozone Layer. The June 1990 London Amendments to the Protocol require the total phaseout of various CFCs by the year 2000, including CFC-113. In 1987, the Environmental Protection Agency and the Department of Defense (DOD) created an Ad Hoc Solvents Working Group to develop a benchmark program to test CFC alternatives. Manufacturers, academics, and government officials initiated a strategy to switch military specifications from prescribing particular production processes, Including CFC use, to procurement standards based on product performance. One estimate concluded that at one time nearly 2,000 military specifications or standards required CFC cleaning.

One result of the Working Group's efforts was creation of MIL-STD-2000 Rev. A, a military standard on soldered electronic assemblies that allows contractors—with adequate documented testing and evaluation—to use alternatives to CFC solvents. Most other DOD procurement documents referencing ODSs have also been revised.[1] DOD also cooperates with NATO and other foreign militaries on military standards and ODS alternatives. These performance-based revisions have removed impediments to the adoption of CFC-113 alternatives by manufacturers. More generally, they remove the impediments to innovation created by procurement standards that constrain manufacturers' ability and incentives to try new processes and materials.

SOURCE: Alan Miller, Pamela Wexler, and Susan Conbere, "Commercializing Alternatives for CFC-113 Solvent Applications, " unpublished contractor report prepared for the Off Ice of Technology Assessment, U S Congress, Washington, DC, May 16, 1995

[1] U.S. Air Force Materiel Command, *Specifications and Standards Revision Tracking System DOD Revision Summary Report,* Mar 271995, cited in Alan Miller, Pamela Wexler, and Susan Conbere, "Commercializing Alternates For CFC-113 Solvent Applications, " unpublished contractor report prepared for the Off Ice of Technology Assessment, U S Congress, Washington, DC, May 16, 1995

In sum, government does, at times, influence the standards-setting process. Cases in which government has attempted to facilitate industry's own attempts to set standards, or in which it has used its procurement policies to tip the balance in favor of a proposed standard, appear to have met with success. Attempts to unilaterally impose standards on commercial industry have met resistance from private industry whose interests differ from those of the government.

SCIENTIFIC RESEARCH

Basic scientific research is a key resource for successful innovation, providing scientific knowledge to support the development of new products,

TABLE 3-2: U.S. R&D Performance by Sector, 1994 (in billions of dollars and percent of total)

Performer	Basic research		Applied research		Development		Total R&D	
Industry	$97	31 %	$283	69%	$858	85%	$123.8	72%
Government	27	9	4,9	12	96	10	17.2	10
University	137	54	52	13	16	2	20.5	12
Other[a]	51	16	27	7	33	3	11.1	6
Total	$312	10070	$410	10070	$100,4	10070	$1726	100%

[a] Includes nonprofit institutions and federally funded research and development centers run by colleges and universities.
NOTE Totals may not add because of rounding

SOURCE National Science Foundation, *National Patterns of R&D Resources 7994,* NSF *95-304* (Arlington, VA 1995) pp. 57-69.

processes and services. For example, advances in the nascent biotechnology industry rely heavily on advances in genetics and biochemistry; and early advances in electronics were based on new insight into solid state physics. Yet, firms invest less in research than economic theory suggests would be optimal for society as a whole.[28] This underinvestment is due largely to problems of *appropriability,* the ability of firms to capture the benefits of their research efforts. Basic research is often far more costly to produce than to diffuse or imitate, so companies cannot easily prevent their competitors from benefiting from their research activities. Nor can they hope to fully exploit all the knowledge they could gain from basic research. Several studies confirm that companies rely on outside sources of knowledge and technical inventions for the vast majority of their commercially significant new products.[29]

Firms conduct basic research for a number of reasons—to gain first-mover advantages; to help them better plan and interpret the results of applied research programs; and, more importantly, to enable them to better evaluate and exploit knowledge produced elsewhere[30]—but the conduct of basic research in the United States has fallen mostly to universities. University-performed research accounted for only 12 percent of the nation's total R&D spending in 1994, but amounted to 54 percent of all basic research (table 3-2). Universities allocated two-thirds of their R&D to basic research, compared with only 8 percent for development activities. Industry, in contrast, skews its R&D heavily toward development. In 1994, almost 70 percent of industry-performed R&D was in development, versus only 8 percent in basic research. Government laboratories performed less than 10 percent of the nation R&Din 1994, with over half of the effort in development. Most of this work supports government missions that are of limited commercial interest.

University research plays several roles in the development of industrial technology. In immature industries such as biotechnology, university research is often the source of new inventions. University researchers accounted for over 18 percent of the patents in genetic engineering in 1990 and had high shares in some related patent classes (table 3-3). Other chemical and biological research, though rarely the source of new drugs, identifies the types of reactions pharmaceutical companies should look for in their quest for new

[28] Kenneth Arrow, "Economic Welfare and the Allocation of Resources for Invention," in *The Rate and Direction of Inventive Activity* (Princeton, NJ: Princeton University Press, 1962); and Richard Nelson, "The Simple Economics of Basic Research." *Journal of Political Economy,* June 1959.

[29] R.S. Rosenbloom, '"Product Innovation in a Scientific Age," ch. 23 in *New Ideas for Successful Marketing,* Proceedings of the 1966 World Congress, American Marketing Association, Chicago, IL, 1966; J. M. Utterback, "Innovation in Industry and the Diffusion of Technology," *Science,* Feb. 15.1974, pp. 620-626; C. Freeman, *The Economics of Industrial Innovation* (Cambridge, MA: MIT Press, 1982).

[30] Nathan Rosenberg, "Why Do Firms Do Basic Research (With Their Own Money)?" *Research Policy, vol. 19, 1990,* pp. 165-174

TABLE 3-3: University Share of Patents in Technologies Relevant to Industry, 1990

Patent class	Total patents	University patents	University share
Genetic engineering/recombinant DNA	321	58	18.1%
Molecular biology and microbiology	1,417	171	121
Superconductor technology	233	25	107
Drugs: bio-affecting and body-treating	1,490	147	99
Robots	251	12	48
Semiconductor device manufacturing	755	23	30
Active solid state devices (e g , transistors)	1,535	34	22
Optics: systems and elements	2,280	41	18
Electrical computers and data processing	6,474	53	08
Communications	2,026	14	07

SOURCE: Nathan Rosenberg and Richard R Nelson, "American Universities and Technical Advance in Industry" *Research Policy,* vol. 23, No. 3 May 1994, p 339, from unpublished data gathered by Jonathan Putnam and Richard Nelson

drugs, and enables companies to better assess the possible uses for a drug they are testing. In more mature industries, such as electronics, that are characterized by greater emphasis on incremental innovation and improvement in existing product lines, innovation is less dependent on academic research. Universities held less than 3 percent of the patents in fields such as semiconductors, computers, and communications in 1990. Nevertheless, academic research serves as the source of revolutionary new technologies that provide the impetus for entirely new types of products in these fields.[31]

The linkages between university research and industrial technology vary considerably across academic disciplines and industries (see table 3-4). Survey data indicate that in the pharmaceuticals industry, 27 percent of new products and 29 percent of new processes introduced between 1975 and 1985 could not have been developed without substantial delay without university research. Another 17 percent of products and 8 percent of processes relied substantially on recent academic findings. In other fields, the linkages are not as strong. In the information processing, scientific instruments, and electronics industries, only 11, 16, and 6 percent, respectively, of new products were highly dependent on academic research.[32]

As companies redirect their own R&D funding toward shorter term projects, they are increasing their reliance on university research. Between 1974 and 1994, the percentage of university R&D funded by industry increased from 3.1 percent to 7.1 percent, while total university R&D more than doubled from $8.75 billion to $20.5 billion.[33] Recent estimates indicate that 19 percent of all university research is conducted in programs that have significant industrial participation.[34] Except in rare cases in which university R&D substitutes for industrial R&D (typically in industries that do not support much in-house R&D), the vast majority of this work involves basic and applied research.

[31] Government-University -Industry Research Roundtable, *New Alliances and Partnerships in American Science and Engineering,* (Washington, DC: National Academy Press, 1986), as reported in Nathan Rosenberg and Richard Nelson, "American Universities and Technical Advance in Industry," *Research Policy,* vol. *23,* 1994, p. 343.

[32] Edwin Mansfieid, "Academic Research and Industrial Innovation," *Research Policy,* vol. 20, No. 1, February 1991. pp. 1-12.

[33] National Science Foundation, *National Patterns of R&D Resources, 1994,* NSF 95-304 (Arlington, VA: 1995), table B-2.

[34] Wes Cohen et al., *University-Industry Research Centers in the United States,* report to the Ford Foundation, 1993.

TABLE 3-4: Percentage of New Innovations Based on Recent Academic Research, 1975-1985

Industry	Percentage that could not have been developed (without substantial delay) without recent academic research		Additional Percentage developed with substantial aid from recent academic research	
	Products	*Processes*	*Products*	*Processes*
Information processing	11%	11%	17%	16%
Electronics	6	3	3	4
Chemicals	4	2	4	4
Instruments	16	2	5	1
Pharmaceuticals	27	29	17	8
Metals	13	12	9	9
Petroleum	1	1	1	1
Average	1170	8%	8%	6%

SOURCE: Edwin Mansfield, "Academic Research and Industrial Innovation," *Research Policy,* vol. 20, No *1,* February 1991, table 1, p 2

FINANCING

New technologies often require decades to move from the laboratory to the marketplace, and costs tend to increase exponentially with each step forward. Availability of capital can, therefore, become a bottleneck for large and small companies alike as they attempt to move promising technologies closer to the marketplace and select among multiple projects that compete for limited resources. Firms differ in the types of financing they seek and attract. Large, established firms tend to finance innovation from revenues generated by sales of existing products, but corporate decisions regarding resource allocation are influenced by the structure of external capital markets and the expectations of investors. Large, established firms can also issue a new stock series to raise additional capital. Small startup firms, in contrast, tend to finance innovation with their own savings, venture capital, and wealthy investors referred to as *angels.* Each of these sources has its own strengths and weaknesses that reflect the differing relationships between investors and innovators.

■ Sources of Financing

Government and industry share responsibility for funding innovation and commercialization in the United States. Public institutions tend to play a major role in financing basic scientific or technical research, whereas primarily private capital supports company efforts to transform basic knowledge into proprietary commercial applications. Government expenditures for R&D totaled $62.2 billion in 1994, representing just over one-third of total R&D (table 3-5). Some$18 billion of this funding went to basic research, making the government the largest supporter of basic research in the country, accounting for more than half of all such funding. Industry funded 59 percent of total R&D, but spent about 69 percent of its resources on development activities and another 23 percent on applied research. Only 8 percent of industry funding went toward basic research.

Federal R&D funding has declined in both real and relative terms since 1987. Between 1987 and 1994, federal expenditures declined from $73 billion to $62 billion (in constant 1994 dollars), falling from 46 percent to 36 percent of total U.S.

TABLE 3-5: U.S. R&D Expenditures by Source of Funding, 1994 (billions of dollars and percent of total)

Source	Basic research		Applied research		Development		Total R&D	
Industry	$8,2	26%	$23.9	58%	$70.0	70.0%	$1021	59%
Government	18,2	58	14,5	35	29.6	29.0	622	36
University	3.3	11	1.7	4	0.4	0.4	5.3	3
Other[a]	1,5	5	1 0	2	0 5	0 5	3 0	2
Total --	$31.2	100'%0	$41.0	100?40	$1004	100%	$172.6	10070

[a]Includes nonprofit institutions and federally funded research and development centers run by colleges and universities.
NOTE: Totals may not add because of rounding

SOURCE: National Science Foundation, *National Patterns of R&D Resources, 7994,* NSF 95-304 (Arlington, VA: 1995), pp. 54-68.

R&D.[35] This trend places greater demand on private sources of funding. Private financiers typically provide equity rather than debt financing for new technology development. One reason is that technology development typically offers little collateral for a loan. Failed R&D projects generally do not generate any salable property, physical or intellectual. Specialized facilities and equipment purchased for technology development often have low resale value, and can be difficult to resell at all.[36] Also, technology development tends to be riskier than other sorts of investment. Not only do new technology ventures need sound business plans, appropriate marketing strategies, and requisite management and business skills in order to succeed; they must also develop the technology sufficiently to turn it into a product. Potential investors often lack the ability to evaluate a project technical merits.

Private funding for innovation ultimately derives from national savings.[37] U.S. savings rates, however, lag those of its major economic competitors. Between 1990 and 1992, the U.S. national savings rate averaged 2 percent of GDP, compared with 20 percent for Japan, 11 percent for Germany, 8 percent for France, and 3 percent for the United Kingdom.[38] This lower rate results in part from the need to pay interest on the national debt, which amounted to roughly 4 percent of GDP. U.S. investments in nonresidential fixed capital have also lagged those of its primary competitors since at least 1970. Between 1990 and 1992, nonresidential fixed investment (including government capital expenditures) in the United States averaged 12 percent of GDP, compared with 26 percent for Japan, 15 percent for France and Germany, 14 percent for Canada, and 13 percent for the United Kingdom.[39] This may result, in part, from the U.S. tax system, which taxes corporate investments twice: once as corporate profits and once as distributed dividends.

External Capital Markets

Differences in the structure of capital markets tend to make U.S. providers of equity capital less patient and less knowledgeable about the internal operations of particular firms than capital providers in Japan and Germany. In Japan, most large

[35] National Science Foundation, op. cit., footnote 33.

[36] Stephen J. Kline and Nathan Rosenberg, "An Overview of Innovation," in *The Positive Sum Strategy,* Ralph Landau and Nathan Rosenberg (eds.) (Washington, DC: National Academy Press, 1986), p. 300.

[37] Foreign investment in the U.S. economy during 1990-92 averaged less than 1 percent of GDP. National Research Council, Board on Science, Technology, and Economic Policy, *Investing for Productivity and Prosperity* (Washington, DC: National Academy Press, 1994), p. 15, table 2.

[38] Ibid., p. 16, table 3. Earlier years show a similar pattern.

[39] Ibid.,p. 4, table 4, citing Organisation for Economic Cooperation and Development, Annual and Quarterly National Accounts.

company stock is held by *keiretsu*, or groups of related industrial firms that give preference to other group members in procuring supplies and services.[40] Each group member has a vested interest in other group members' long-term success and tends to hold the stock for long periods of time, rather than trading it to win short-term profits. In addition, both Japanese and German banks may hold equity in borrowing firms, giving them a further interest in the firms' long-term success. Bankers also tend to understand in detail the business of firms they lend to, which can give them confidence in a firm's long-term viability in the face of short-term setbacks. Both banks and stable shareholders often have close relationships with the firm's management and offer them advice. Of course, such arrangements can have negative consequences if the bank within the *keiretsu* or closely affiliated with a particular company fails.

In the United States, company stock is less closely held; most is readily traded by investors looking for short-term gain. In fact, most publicly traded stock is owned by managed funds, such as pension funds and mutual funds, whose managers are evaluated on the fund's quarterly performance. U.S. tax laws provide no incentive to hold stocks for sustained periods, as capital gains tax rates no longer distinguish between stocks held for shorter or longer periods of time. The average period a stock is held has declined from over seven years in 1960 to just two years in 1990.[41] U.S. banks are prohibited from owning equity in their clients, and typically know little about their clients' business; therefore they add little stability to the market. While the effects of rapid turnover are hard to deduce, the frequent revaluing of stock prices, combined with an obligation to protect shareholder interests, provides an incentive for company managers to favor short-term returns over long-term investments such as R&D.

On the other hand, the openness of the U.S. capital system allows mobilization of large amounts of capital, and enables small firms better opportunities to raise money on the stock market through an initial public offering. This ability motivates a vital venture capital industry—unparalleled abroad—to invest in risky startup companies. New firms rely on venture capital and angels—wealthy individuals who invest in small companies—for much of their startup funding because they have no product, track record, or earnings. They must sell investors on the viability of their idea and the competence of their people. Both the venture capital and angel markets share some attributes with the overall financial systems of Japan and Germany in that investors are patient, they are well informed about the firms they invest in, and they have a say in management decisions.[42] However, both are limited in their ability to help startup firms.

Venture Capital and Angel Financing

Small startup companies in the United States often look to the venture capital markets and wealthy *angels* for their capital needs. These markets bear some resemblance to external capital markets in Japan and Germany. Investors tend to be patient, are knowledgeable about the firms in which they invest, and provide management expertise. Yet, these markets are much smaller than other capital sources for innovation.

Venture capital is widely viewed as a strength of the U.S. system of innovation. The total value of existing venture capital investments in U.S.

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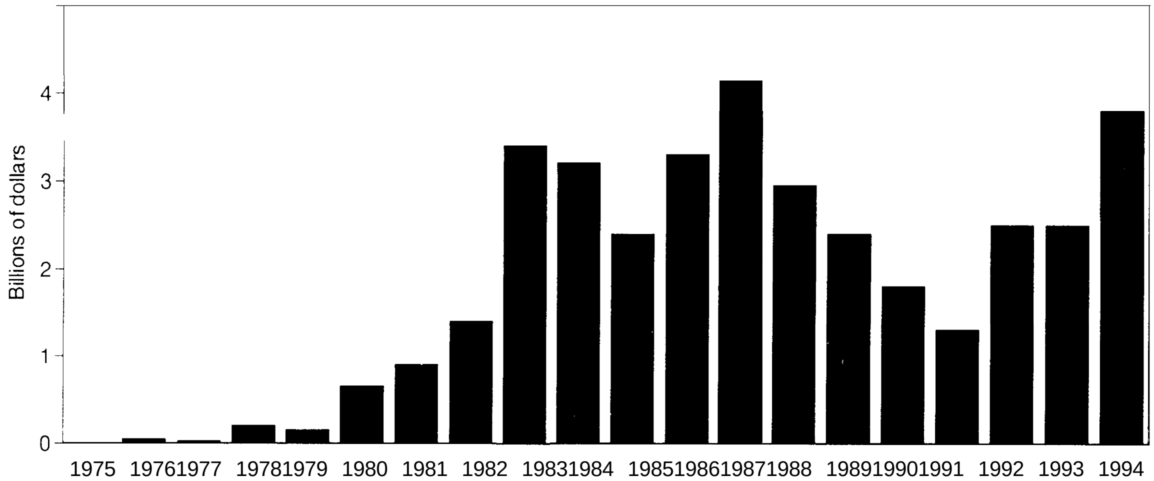
[40] Typically, a minority portion of the target firm's stock is sold on the open market. While that portion is frequently traded and can experience large price swings, it tends to have little effect on the firm's behavior. Japan is moving somewhat in the direction of the United States. Long-term investors are reconsidering their strategies and, in some cases, selling stock, partly to gain needed liquidity during Japan's current recession. R. Steiner and J. Sapsford, "Japanese Investors Get Choosy About Stocks, Depressing the Market," *Wall Street Journal*. June 28, 1995, p. A1.

[41] Michael Porter, *Capital Choices: Changing the Way America Invests in Industry,* report presented to the Council on Competitiveness and cosponsored by the Harvard Business School (Washington, DC: Council on Competitiveness, June 1992), p. 5.

[42] Although neither Japan nor Germany has a robust venture capital market for financing startup companies.

FIGURE 3-1: New Commitments to Private Venture Capital Funds, 1975-1994



SOURCE: Venture Economics, Inc., as cited in William D. Bygrave and Jeffry A. Timmons, *Venture Capital at the Crossroads* (Boston, MA Harvard Business School Press, 1992), p 26, and in Lisa Vincenti, "Fund Raising Renaissance," *Venture Capital Journal,* Feb. 1995, p *40*

firms was $35 billion in 1992, more than 10 times that of Japan or Germany.[43] Venture capital firms raise money from institutions and individuals to invest in relatively high-risk, but potentially high-reward, new firms. In return, firms receiving funding from venture capitalists transfer an average of 69 percent of their equity to venture capital firms.[44] Within a fixed period of time, typically seven to 10 years for successful investments, venture capitalists liquidate their holdings, often through private buyouts or initial public offerings in the stock market. Because their compensation depends on the performance of their investments, venture capitalists not only have strong stakes in the success of firms in their portfolio, but they have strong incentives to cut losses on firms that do not perform satisfactorily. Venture capital helped spawn many startup companies such as Apple, Digital Equipment Corp., Genentech, and Intel by providing not only early-stage financing, but managerial assistance to help firms develop business plans, manage technology and product development, and deal with regulations in areas such as taxes, working conditions, and environment.

Venture capital can support only a limited number of technology-based firms at any given time. While new venture capital commitments have nearly tripled since 1991, reaching $3.8 billion in 1994, they are still only slightly larger than the R&D budget of IBM Corp. (figure 3-1). Only 10 to 20 percent of the new technology ventures started in the United States each year receive venture capital. Far greater resources are invested by entrepreneurs themselves, larger companies, and angels. In addition, venture capitalists appear to be backing away from capital-intensive industries like electronics and shifting their attention toward

[43] Richard Florida and Donald F. Smith, Jr., "Keep the Government Out Of Venture Capital," *Issues in Science and Technology,* summer 1993. p. 62.

[44] Coopers & Lybrand, *Fifth Annual Economic Impact of Venture Capital Study,* 1995, as cited in Gene Koprowski, "Venture Capitalists Taking Big Chunks Of Startups," *HPCC Week,* Apr. 20, 1995, p. 7.

industries like biotechnology and software that have lower startup costs.[45] Despite growth in seed capital investments in 1994, venture capitalists also appear to be moving toward funding at later stages, reducing their emphasis on seed capital.[46]

Angels—affluent individual investors—play an important role in seeding startup firms, infusing an estimated $10 billion to 30 billion per year into firms at the earliest stages of development.[47] In contrast to the market for venture capital, the market for angel funding is informal and fragmented, limiting its potential ability to help startup firms. Angel investors typically learn about investment opportunities through accidents of geography and personal acquaintances. More formal mechanisms for matching angels to needy companies, or for pooling the resources of several angels for a single investment, do not exist on a large scale. Some researchers estimate that up to $300 billion in angel funding could be tapped if information about investments could be targeted to potential investors.[48]

Several initial efforts have been made to help entrepreneurs and angels find each other. In 1984, the Venture Capital Network, Inc. (VCN) was established as a not-for-profit affiliate of the Center for Venture Research at the University of New Hampshire. VCN began to build databases of entrepreneurs and angels and to provide selective introductions. VCN moved to the Massachusetts Institute of Technology in 1990, and was renamed the Technology Capital Network, Inc. in 1992. Between 1984 and 1990, the program served 1,200 entrepreneurs and 800 investors. It made 3,500 introductions that led to at least 31 ventures (of which 80 percent were technology-based), raising a total of $12 million from 50 investors. VCN helped initiate six similar networks in the United States and Canada.[49] Another effort to facilitate angel financial markets is The Capital Network (TCN), established by the IC² Institute at the University of Texas and located at the Austin Technology Incubator. TCN provides a computerized information clearinghouse and introduction service that matched up nearly $25 million in investments over the past five years.

Small Business Assistance Programs

Small firms also receive assistance from technology incubators (see box 3-4) and from federal programs that address entrepreneurial needs. Many of these latter programs, however, are not targeted to the specific needs of high-technology firms. Programs operated by the Small Business Administration (SBA) serve small firms, whether or not the firms focus on high-technology work, and they serve small, high-technology firms without specifically targeting startups. For example, the SBA operates a number of small business development centers (SBDCs) that provide small firms with an array of services—from expert referrals to export assistance—but they often lack the exper-

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[45] Of new venture capital commitments in 1994, 28 percent went to biotechnology, 14 percent to software, 14 percent to media and communications, and 12 percent to semiconductors and electronics. Coopers & Lybrand, ibid.

[46] OTA interviews with venture capitalists and managers of high-technology startups.

[47] J. Freear, J. Sohl, and W. Wetzel, "The Private Investor Market for Venture Capital," *The Financier: ACMT*, vol. 1, No. 2, May 1994, pp. 7-15.

[48] J. Freear, J. Sohl, and W. Wetzel, "Angels and Non-Angels: Are There Differences?" *Journal of Business Venturing*, vol. 9, pp. 109-123.

[49] J. Freear, J. Sohl, and W. Wetzel, "The Private Investor Market for Venture Capital," *The Financier: ACMT*, vol. 1, No. 2, May 1994, pp. 7-15.

BOX 3-4: Business In

Often endowed with both public and private support, a business incubator helps entrepreneurs by providing: 1) low-cost office space; 2) shared support services; 3) assistance in developing business strategy and in coping with practical concerns such as government regulations; and 4) access to capital sources, technical expertise, and business partners. Incubators form a hub for entrepreneurial interaction and business development by connecting investors, business groups, universities, and public agencies with new firms.[1] About 20 to 25 percent of the more than 700 existing incubators specifically assist new high-technology firms. Many are located at or near universities or research parks, bringing entrepreneurs close to valuable technical resources and making them a natural home for commercialization efforts arising from Innovations at academic laboratories.

Data on the success rates of technology incubator clients are sparse, partly because two-thirds of incubators are less than five years old and have few, if any, graduates, However, evidence suggests that they contribute to the creation and development of technology-based firms. One study showed that graduates of the selected incubators experienced an average annual growth rate of 166 percent in sales and 49 percent in employment between 1986 and 1990.2

Although incubators are intended to breed successful companies, critics charge that they offer Iife support to firms that would and should ordinarily fail. While some incubators have graduated dozens of firms, others have experienced only failures. Moreover, despite their expressed preference for high-technology firms, few Incubators can provide technology-based firms with the expertise and resources they need to flourish,[3] To succeed, incubators must provide the resources and services that clients need, Some say that an incubator, by example, can show how to run an efficient, customer-oriented firm. To succeed, an incubator also needs clients committed to business success, rather than entrepreneurs content to remain small [4]

The federal government currently assists incubators. Regional offices of the Department of Commerce's Economic Development Administration support feasibility studies, technical assistance, and construction costs for Incubators sponsored by both public and nonprofit organizations.[5] Incentives and assistance have been offered to help link disparate public and private resource providers into incubators and other small business assistance programs. Small Business Development Centers perform some of these services, and other entitles, such as the federal/state-supported TEXAS-ONE initiative and the private Coopers & Lybrand Batorlink, provide electronic links among small businesses, research organizations, incubators, and other resources. A possible future federal role would be to work with the National Business Incubators Association to develop criteria and certification procedures to assure quality services to clients.

SOURCE Office of Technology Assessment, 1995

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[1] S. Birley, "The Role of Networks in the Entrepreneurial Process, " *Journal of Business Venturing,* vol. 1, No. 1, winter 1985, pp. 107-117, R. Smilor and M.D. GiII.*The New Business Incubator* (Lexington, MA: Lexington Books, 1986); M.P. Rice, *Linking the Performance of the Rensselaer Incubator Program and the Performance of its Participating Companies,* paper presented at the 1994 Babson Entrepreneurship Research Conference, University of Houston, Houston, TX, June 11, 1994.

[2] S.A. Mian, "U.S. University-Sponsored Technology Incubators: An Overview of Management, Policies, and Performance. " *Technovation,* vol. 14, *No 8,* 1994, pp. 515-528.

[3] Johanna Ambrosio, "Incubators Nurture Start-up Firms, " *Computerworld,* Sept 16, 1991, pp 105, 112; G.G. Udell, "Strategies for Stimulating Home-Grown Technology-Based Economic Development, " *Business Horizons,* November-December 1988, pp 60-64, see also, *The State of the Business Incubation Industry 7997* (Athens, OH National Business Incubation Association). In a mid-1980's study, 86 percent of responding incubators indicated a preference for high technology. Cited in R. Smilor, "Commercializing Technology Through New Business Incubators, " *Research Management* September-October 1987, pp 36-41

[4] M.P. Rice and J B Matthews, *Growing New Ventures—Creating New Jobs Principles and Practices of Successful Business Incubation,* (Kansas City, KS CEL Kauffman Foundation, forthcoming 1995), Smilor, ibid., Rice, op. cit., footnote 1.

[5] About 10 percent of the Economic Development Administration's work is related to assisting incubators, Rick Sebenoler, Technical Assistance Program, Economic Development Administration, U.S. Department of Commerce, Austin, TX, personal communication, Aug 22, 1995.

tise and contacts needed in many high-technology sectors.[50]

The SBA also authorizes and supports Small Business Investment Companies (SBICs) that invest in small business through long-term loans and equity stakes. Although data are limited, available evidence indicates that SBICs help channel investment to new high-technology firms. It is estimated that of the $11 billion invested in over 57,000 small businesses between 1958 and 1992, 60 percent went to firms less than three years old.[51] Over the same period, approximately $1.6 billion of SBIC investments went into high-technology enterprises.[52] SBICs often finance low-collateral business activities—including R&D, marketing, and self-acquisition—that are crucial to such firms.[53]

Small, high-technology businesses are the target of the federal Small Business Innovative Research (SBIR) program. The program requires large federal agencies to reserve a percentage of their extramural research budget for competitive grants to small firms (see box 3-5). The SBIR program provides critical funding, as well as the opportunity to further R&D and product development, to many firms in the early stages of their development. Many small businesses also participate in other federally sponsored cooperative technology programs, such as the Advanced Technology Program (ATP), which funds *precompetitive* research programs. Approximately half of the ATP awards to date have gone to small businesses or joint ventures led by small businesses.[54]

HUMAN RESOURCES

Human resources are important to innovation because new technologies imply new ways of performing tasks related to research, manufacturing, or marketing.[55] Successful innovation requires that entrepreneurs assemble a team of well-trained scientists, engineers, technicians, managers, and marketers who develop new technologies; incorporate them into products; manufacture them in a way that is timely, cost-effective, and responsive to the market; and sell them. Training workers with these diverse skills is the responsibility of different institutions, both public and private.

The formal education system, from kindergarten through graduate school, provides the basic

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[50] G. G. Udell, "Strategies for Stimulating Home-Grown Technology-Based Economic Development," *Business Horizons*, November-December 1988, p. 63; in interviews with OTA, administrators of technology incubators and state technology programs stated that high-tech firms typically sought assistance from SBDCs only after pursuing the support of a technology incubator or state-sponsored technology program. In recent partnerships with other federal agencies, however, the SBDC program combines small business assistance with other agencies' technical resources. For example, SBDC subcenters have been established at 10 National Institute for Standards and Technology (NIST) Manufacturing Technology Centers to bring a greater range of financial and business expertise to the centers' primary manufacturing extension services for small and medium-sized manufacturers; "NIST Manufacturing Centers to Host SBA Experts in Coop Program," *Industrial Engineering*, December 1993, pp. 7-8.

[51] U.S. Congress, Senate, Committee on Small Business, "Hearing on Investment in Critical Technologies Through the Small Business Administration's Existing Financing Programs," 103d Congress, 1st session, June 9, 1993.

[52] This amount is said to have leveraged an additional $7.1 billion from other private sources; ibid. Apple Computer, Cray Research, and Intel received SBIC financing in their early years.

[53] E. Brewer, III, and H. Genay. "Funding Small Business Through the SBIC Program," *Economic Perspectives*. May-June 1994, pp. 22-34. On average, bank-related SBICs raise more private capital and rely less on SBA funding and guarantees than other SBICs.

[54] Of the 24 ATP awards announced in July 1995, 18 of the total 47 participants were small businesses and 13 of the 24 joint ventures were led by small businesses; U.S. Department of Commerce, "NIST Announces 24 New Advanced Technology Program Awards," *Commerce News* press release, Washington, DC, July 13, 1995, p. 30.

[55] For a more in-depth discussion of this subject, see U.S. Congress, Office of Technology Assessment, *Worker Training: Competing in the New International Economy*, OTA-ITE-457 (Washington, DC: U.S. Government Printing Office, September 1990); U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering—A Background Paper*, OTA-BP-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989); and U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988).

BOX 3-5: Small Business Innovative Research Program

The Small Business Innovative Research program (SBIR) seeks to increase the level of small firm participation in federal R&D activities and to improve private sector commercialization of federally developed Innovations. All federal agencies with external R&D budgets greater than $100 million must set aside a specified percentage of this budget for small businesses. ' Although the SBA is the overseeing agency, each participating agency selects areas of research, solicits and chooses proposals, and administers funding. This keeps the SBIR work closely related to each agency's mission. After two phases of SBIR funding, a firm may move its renovation toward commercial markets by seeking private investment and support; although no SBIR funding is available for the third phase, these firms may win production contracts or non-SBIR funding from federal agencies.

Between 1983 and 1993, 11 agencies gave nearly 25,000 Phase I and II awards worth over $3.2 billion to more than 50,000 small firms. Awards enable small firms to expand research, hire new personnel, develop new products, and find new markets and customers. Eighty-four percent of one study's respondents Indicated that their technology would not have been pursued without SBIR assistance. Many SBIR participants are young firms; over 20 percent of Phase I awardees are less than two years old, For most participants established after 1983, SBIR was their first experience with federal R&D programs. In 1989, project administrators judged about half of SBIR projects to be at least equal in quality to other agency R&D, nearly 30 percent were considered better. There was a strong sense at all agencies that SBIR work was more Iikely to be commercialized than other agency-supported R&D.

Evidence suggests that SBIR maybe helping to increase the participation of small firms in federal R&D activities In 1982, the National Science Foundation estimated that small firms' share of federal R&D was 2.8 percent. By 1991, that share had reached 3.7 percent. Commercialization, too, may be facilitated. By 1992, SBIR firms had received $471 million in sales and $646 million in additional development funding for Phase Ill (commercialization) work. While the sales figure is modest compared to the $3.2 billion in federal Phase I and Phase II investments, many investments are still maturing. A total of 27 percent of the firms responding to one study had commercialized or expected to commercialize SBIR related work in the near future.

There are some downsides, however. A large percentage of sales realized through SBIR work is derived from the public rather than the private sector. In 1991, the majority of SBIR participants earned 65 percent or more of their sales from government markets. In addition, because SBIR is based on agencies' R&D needs, award selection is driven by technology, not by markets; market concerns are left for Phase Ill. By this point, however, the deck may be stacked against a number of innovations with little or no identifiable commercial appeal. Also, while some grant recipients may seek commercialization, a large portion may be Interested primarily in further research. Some recent agency efforts have taken modest steps to increase the priority on commercialization. The Department of Energy has provided commercialization training sessions, and in 1994 the Navy required firms to submit a commercialization plan before receiving the last 20 percent of a phase II award. Another concern is that some firms have received several duplicative grants from different agencies

SOURCES: U.S. Congress, General Accounting Office, *Federal Research: Interim Report on the Small Business Innovation Research Program,* GAO/T-RCED-95-154 (Gaithersburg, MD: Apr. 6, 1995), U.S. Small Business Administration, *Small Business. Building America's Future, Results of a Three-Year Commercialization Study of the SBIR Program* (Washington, DC 1991), p 5, U S Congress, General Accounting Office, *Federal Research' Small Business Innovation Research Participants Give Program High Marks,* GAO-RCED-87-161-BR (Washington, DC July 1987), pp. 13-30,35-38, U S Congress, General Accounting Office, *Federal Research: Assessment of Small Business Innovation Research Programs,* GAO/RCED-89-39 (Washington, DC January 1989), and Thomas Enterprises, Inc., *Small Business Innovation Research (SBIR) Program Analysis,* report prepared for the Office of Technology Commercialization, U.S. Department of Commerce, Washington, DC, Jan. 17, 1995, pp. 8-9

[1] Public Laws 97-219, 99-443, and 102-564 The percentage rose annually from O 2 percent m 1983 to 1 25 percent in 1986, increased to 1 5 percent in 1993 and 20 percent in 1995, and is scheduled to increase to 25 percent in 1997.

[2] U.S. Congress, General Accounting Office, *Federal Research: Interim Report on the Small Business Innovation Research program,* GAO/T-RCED-95-154 (Gaithersburg, MD: Apr. 6, 1995), pp. 4-5

[3] Ibid., pp. 5-6.

skills that workers can apply to innovation. While U.S. universities are generally considered the best in the world, especially in technical fields, they have also been criticized for training graduates too narrowly, especially engineering graduates who often receive little training in manufacturing processes, product design (including design-for-manufacture and design-to-cost), and teamwork. Moreover, in international comparisons of achievement in mathematics and science, U.S. schools from kindergarten through high school perform poorly compared with other industrialized and industrializing countries, and often fail to impart the basic reading and math skills required in the workplace.

Workplace education supplements formal education, as workers learn through experience and formal training programs. For emerging technologies in particular, many of the skills needed for commercial success are not available in the formal education system, but are developed instead by firms engaged in proprietary R&D programs. Few engineering graduates could develop a new device using high-temperature superconductors without the guidance of a more experienced engineer; similarly, the skills of managers tend to improve with experience. Universities, research institutes, and corporations recruit and train people in skills related to innovation, whether in research techniques, project management, or production. Job transfers and workforce mobility tend to disseminate these skills throughout the industry, but, at the same time, reduce the ability of organizations to capture the benefits of their investments in training and education.

Labor force skills are expanded through industry conferences, technical committees, trade publications, and technical journals, which provide an opportunity for industry participants to exchange ideas and share knowledge. Information is also exchanged through "invisible colleges" or informal networks of engineers within particular industries who exchange know-how. Studies of steel-making minimills reveal that engineers frequently trade information that is not critical to their companies' competitive advantage.[56] This is especially useful when the particular piece of information is too small to justify a negotiated license or exchange because it effectively distributes technical information among participants in an industry. Recent evidence indicates that differences in the degree to which researchers share information can influence a region's ability to successfully innovate and commercialize new technologies. The greater success of California's Silicon Valley compared with Boston's Route 128 during the late 1980s and early 1990s has been attributed, in part, to the more open culture of Silicon Valley, which facilitated information sharing.[57]

TECHNOLOGY DEVELOPMENT

Development of new technology—as well as new products, processes, and services based on new technology—is the central activity of technological innovation. Private corporations must appropriate basic knowledge of science, technology, and markets and convert it into proprietary knowledge through applied research and development. This process is best characterized as a trial-and-error search for a viable set of product attributes that meets market demand, and for technologies capable of providing those attributes at a cost the market will support.

While the private sector bears primary responsibility for developing commercial technologies in the United States, government activities influence those efforts. Products and technologies developed by or for the government often find commercial application. Most U.S. jet engines

[56] Eric von Hippel, "Cooperation Between Rivals: Informal Know-How Trading," *Research Policy*, vol.16, 1987, pp. 291-302.

[57] AnnaLee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge, MA: Harvard University Press, 1994).

used on commercial aircraft today derive from military antecedents,[58] as do other aircraft technologies such as fly-by-wire control systems and swept-back wings. The Internet derives largely from ARPANET, a national computer network developed in the early 1970s by DOD's Advanced Research Projects Agency (ARPA). Numerous other examples of such "spin-off" exist in industries such as aircraft, electronics, and materials that serve important government missions. Though spin-off has declined over time as military and commercial requirements have diverged and commercial markets have developed,[59] military technology—and government technology more generally—contributes substantially to the nation's stock of technical knowledge and to its current competitive position.

Federal laboratories also contribute to commercial technology development. Several hundred federally funded research and development centers (FFRDCs)[60] and government-owned laboratories conducted $22.3 billion in R&D in 1994.[61] Since 1980, numerous attempts have been made to facilitate the transfer of technologies from these labs to the commercial sector. The Stevenson-Wydler Technology Innovation Act of 1980 requires most federal laboratories to establish Offices of Research and Technology Applications to promote technology transfer and to allocate 0.5 percent of their R&D budgets to technology transfer activities. The Federal Technology Transfer Act of 1986 amended Stevenson-Wydler to allow government-owned and -operated laboratories to enter into cooperative research and development agreements (CRADAs) with private industry. Under this authority, which was extended to government-owned, contractor-operated labs in 1989, government laboratories were allowed to contribute personnel, equipment, and other nonfinancial resources to projects undertaken jointly with industry. Such legislation has resulted in thousands of CRADAs to date with firms working in the automotive, biotechnology, computer, and semiconductor industries, to name a few.

NETWORKS AND LINKAGES

In developing new products and processes, firms must create linkages to sources of new knowledge and providers of key components for their products. These linkages serve several purposes for the innovating firm, allowing it to: 1) spread the costs and risks associated with innovation among a greater number of organizations; 2) gain access to new research results and technological capabilities for innovation efforts; 3) acquire key components of a new product or process; and 4) gain access to complementary assets in manufacturing, marketing, and distribution. Acquiring such resources means linking with other developers of similar products, suppliers of critical components, and university researchers.

Firms often link together to share the cost and risk associated with innovation. New commercial aircraft easily cost over $1 billion to develop, as do the jet engines that power them. Estimates of the R&D costs required for next-generation semiconductor manufacturing, which will use 10- to 12-inch wafers of silicon, start at $3 billion, and

[58] General Electric's CF6 engine and Pratt & Whitney's JT9, both used to power the 747 aircraft, derive from engines designed or built for military transports. The core of GE's newest engine, the CFM-56, built in collaboration with the French firm, SNECMA, derives from the engine used on the B-1 bomber. Jerry Sheehan, *Commercialization and Transfer of Technology in the U.S. Jet Aircraft Engine Industry,* unpublished master's thesis, Massachusetts Institute of Technology, June 1991.

[59] Alic et al., op. cit., footnote 17.

[60] FFRDCs are research organizations owned and operated by nongovernment organizations (industry or universities) that receive their funding from the federal government.

[61] National Science Foundation, *National Patterns of R&D Resources,* 1994 (Arlington, VA: 1995), table B-2. The figure is the sum of R&D performed by government and by university-run FFRDCs.

the cost of individual semiconductor fabrication facilities tops $1 billion.[62] Pharmaceuticals companies often spend more than $200 million to get a new drug to market.[63] At the same time, innovators face numerous uncertainties in developing new products and processes. The innovation may not work as expected, or it may not be possible to manufacture it with the right combination of price and performance. The market may not develop as rapidly as anticipated—or to the size needed to support profitable manufacture.

Few companies can afford to assume these risks alone. As a result, they rely on alliances, consortia, and suppliers to shoulder some of the burden. Large systems integrators such as Boeing use subcontracting arrangements to spread risk among a large number of suppliers and subcontractors, each of whom is responsible for a portion of the final product that Boeing itself will integrate. Sometimes competitors form alliances to jointly conduct R&D that no one firm could support single-handedly. Even large, diversified firms are finding such alliances necessary to develop next-generation technology. In the semiconductor industry, for example, IBM has teamed with Toshiba and Siemens to develop memory chips capable of storing 256 million bits of information (256 Mbit DRAMs).

Firms also form consortia, such as SEMATECH, the Semiconductor Manufacturing Technology consortium, which finances R&D projects of joint interest to its 11 member companies. Consortia are similar to subcontracts in that multiple participants each perform a part of the overall task; however, they differ in that responsibility for overall project initiation and design is shared, rather than controlled by the system integrator. In some industries, such as aircraft and portions of the electronics industry, international consortia are common. Because these industries have strong economies of scale and high R&D costs, typically just one leading company, or at most a few, resides in any one country. Airbus Industries, for example, is a consortium of several European countries. None was able to independently sustain a viable international presence in large commercial aircraft, but together they formed a viable competitor to Boeing and displaced McDonnell-Douglas as the world's second largest producer of commercial jet aircraft.[64]

Interfirm linkages are also a response to the increasing complexity of new products and processes. Many new products incorporate a large number of individual components. A personal computer, for example, contains a microprocessor, memory, a hard disk drive, a floppy disk or diskette drive, a keyboard, and a monitor. Manufacturing each of these components requires its own individual expertise, as does the process of linking them together in a properly functioning computer. The maker of microprocessors must be skilled in logic design, circuit layout, timing analysis, and semiconductor manufacturing techniques. The disk drive manufacturer must understand the fabrication and operation of read/write heads, servo mechanisms, controllers for maintaining alignment of the read/write heads and the disk, and precision assembly.

Complex technologies such as these—containing many components with numerous linkages between them—now account for the majority of world trade. Between 1970 and 1990, complex products manufactured with complex processes are estimated to have grown from 31 percent to 51

[62] "Scaling the Silicon Summit," *Electronic Engineering Times*, Apr. 4, 1994, p. 30.

[63] This figure represents an average cost for new product development that incorporates both successes and failures. Joseph A. DiMasi, "Risks, Regulation, and Rewards in New Drug Development in the United States," *Regulatory Toxicology and Pharmacology*, vol. 19, 1994, pp. 228-235. For a more detailed discussion of pharmaceuticals' R&D costs, see U.S. Congress, Office of Technology Assessment, op. cit., footnote 12.

[64] It should be noted, however, that Airbus often receives subsidies and preferential treatment from national governments of participating companies.

TABLE 3-6: Source of Innovation for Selected Technologies

	Innovation developed by:			
Innovation type	User	Manufacturer	Supplier	Other
Scientific instruments	77%	23%	O%	O%
Semiconductor and printed circuit board processes	67	21	0	12
Pultrusion processes	*90*	10	0	0
Tractor shovel-related	6	94	0	0
Engineering plastics	10	90	0	0
Plastics additives	8	92	0	0
Industrial gas—using	42	17	33	8
Thermoplastics—using	43	14	36	7
Wire termination equipment	11	33	56	0

SOURCE: Eric von Hippel, *The Sources of Innovation (New* York, NY: Oxford University Press, 1988), table 4-1, pp. 44.

percent of the value of the top 30 exports in world trade. Simple products declined from 58 percent of exports in 1970 to just 12 percent in 1990.[65] Complexity challenges the capabilities of individual companies, often prompting interfirm collaboration. Suppliers are one source of expertise. Not only do they improve the performance or cost of the components they produce, but they often generate innovations in end products that, in turn, stimulate demand for their own components. One study found that suppliers of electrical connectors developed 56 percent of the innovations in wire termination equipment; machine manufacturers developed only 33 percent.[66] Customers or end-users can also be the source of innovation, providing feedback to manufacturers on product improvement (see table 3-6).

MARKETS

Although most new products are developed in response to expressed or anticipated market demand, firms must still actively cultivate markets for their products, especially for those that represent a large departure from current offerings. Sometimes demand is latent. Potential customers may not understand the uses and advantages of a new technology. Or an innovation's usefulness to a customer is dependent on the presence of other users (e.g., a fax machine is only useful if others have fax machines); other technologies (e.g., computer hardware needs software); or other changed circumstances (e.g., a cleaner production process may be more attractive if pollution standards have tightened). Cost can also deter consumers. Technologies that are interesting or products that are technically superior to existing alternatives do not necessarily become market successes. Technical successes can easily be market failures.

Though generally associated with the private sector, market creation can be—and is—influenced by numerous government activities. Institutional arrangements-sometimes involving government policy, as in the case of health care—shape markets for new technology. Regulations, such as those to promote environmental protection and safety, often create incentives to purchase new types of products or services, or

[65] Don Kash and Robert W. Rycroft, "Nurturing Winners with Federal R& D," *Technology Review*, November/December 1993, pp. 58-64. Complex technologies are those with numerous components assembled together, such as computers, automobiles, and industrial machinery. Simple technologies have few assembled components, such as chemicals, drugs, foods, and metals. Simple technologies can sometimes be "high-tech," as in the case of biotechnology-derived drugs and chemicals, and advanced materials.

[66] Eric von Hippel, *The Sources of Innovation* (New York, NY: Oxford University Press, 1988), pp. 36-38.

adopt new manufacturing processes. Government procurement frequently provides initial markets for new products and processes, giving manufacturers an incentive to invest in production capacity and an opportunity to demonstrate product performance and reliability. Changes in the tax code create incentives for users to purchase particular types of products or to vary their consumption patterns accordingly. Many of these influences result from the day-to-day activities of government and exemplify the close intertwining of public- and private-sector forces in shaping technology development and implementation. Although at times government activities have retarded the development of commercial technologies, they also have played a critical role in launching many of the nation's most important industries, from aircraft to semiconductors.

Institutional Issues

Institutional arrangements, often involving government, shape markets for innovative technologies. For instance, the market for medical technologies is shaped by a system in which those who prescribe treatment (physicians and other providers), pay for treatment (usually insurance, Medicare, Medicaid, or health maintenance organizations), and seek treatment for health concerns (patients) are different parties with different incentives. Because of this third-party payer system, markets exist for expensive drugs, devices, and procedures that might otherwise be unaffordable to many who need them. The growing cost-consciousness of payers, consumers, and government is motivating medical technology innovators to analyze coverage and reimbursement issues earlier and more carefully in the development of drugs and devices and in the approval process.

In commercial satellite communications, users benefited from federal establishment of the Communication Satellite Corp. (COMSAT) as a quasi-public company to guide communication satellite system development and oversee U.S. participation in INTELSAT, an international consortium.[67] Leasing arrangements may promote or impede new technologies, depending on circumstances: landlords have little incentive to improve the energy efficiency of their buildings when tenants pay for energy, and tenants may balk at improving a landlord's property at their own expense. In contrast, leasing arrangements for capital goods and office equipment can facilitate the demand for new or upgraded technologies. For potential users, such arrangements lower the costs and risks of trying new technology without diminishing producer incentives for innovation.

Regulation[68]

Regulations can create markets for new technologies by requiring products and processes to meet certain standards. Technological responses to regulation sometimes take the form of discrete devices or services for meeting regulatory requirements (e.g., pollution control devices, safety apparel, automatic seatbelts, or aircraft flight data recorders). In other cases, regulations induce modifications to core products and process technologies, such as "no clean" soldering to avoid solvents, energy-efficient appliances, less toxic pigments, automated processes to avoid worker exposure to hazardous chemicals, and cleaner burning motor fuels. The distinctions between add-on devices and core product or production technologies are fuzzy. It is difficult to discern, for instance, whether redundant avionics and electronic fuel injectors are add-on or integral technologies for aircraft and automobiles, or whether their markets are determined by regulatory demands or good engineering design.

Markets for energy and environmental technologies are especially influenced by regulations, at both the federal and state levels. The Public Utility Regulatory Policy Act (PURPA) of 1978, for example, requires electric utilities to buy power

[67] That industry also benefited from NASA support, including the use of federal launch and other facilities.

[68] This section concentrates on regulations pertinent to the environment, health, and safety.

from nonutility heat and electricity cogenerators and from small power producers at the avoided cost of the utility's power. By doing so, the legislation spawned the establishment of independent power producers and stimulated markets for cogeneration equipment, gas turbines, and certain renewable energy technologies.[69] In a similar vein, California's new automobile regulations (also adopted by Massachusetts and New York) require that zero-emission vehicles account for at least 2 percent of automobile sales from major producers by 1998 and 10 percent by 2003. This policy has led to significant efforts by vehicle manufacturers, suppliers, and industry outsiders to develop automobiles with alternative fuel and power systems. Likewise, the Energy Policy Act of 1992 requires certain federal, state, and private fleets to choose alternatively fueled or powered vehicles for certain percentages of their new vehicle purchases during the late 1990s and early 2000s.[70]

Regulations can also impede technological innovation; in fact, some critics argue that regulatory impediments to innovation undermine the health, safety, and environmental goals they are meant to further.[71] This can happen if particular technologies or products do not meet the requirements of new regulations, or if the costs of doing so are so great as to impede technology development. Product approval requirements, as in the case of pharmaceuticals and pesticides, can delay or prevent new products from coming to market, though such delays are intended to minimize the chance of dangerous or ineffective products being marketed. Regulatory systems that grandfather existing facilities may dissuade investments in new or upgraded technologies if such changes trigger more stringent standards or lengthy permitting processes.

Furthermore, regulations can be written or administered in ways that favor tried-and-true technologies over more uncertain innovations. When permitting procedures are lengthy, costly, or uncertain, firms cannot easily alter processes or introduce new products.[72] Product reviewers and permit writers may act conservatively because of professional risks associated with approving untried technologies. Separate permitting procedures for each state or locality—as is common under environmental regulations—adds cost, time, and uncertainty. Such differentiation fragments the market and burdens new technology vendors—particularly small companies—and can diminish the interest of venture capitalists and other investors.[73] Also, most regulations do not reward innovators who exceed performance requirements.

Regulations that are overly prescriptive can lock in existing technologies to the detriment of other technologies that might also meet or exceed

[69] A number of utilities claim, however, that PURPA and state provisions led them into long-term supply contracts with independent power producers that became less economical as energy prices decreased. Agis Salpukas, "70's Dreams, 90's Realities—Renewable Energy: A Luxury Now. A Necessity Later?" *New York Times*, Apr. 11, 1995, pp. D1, D8; U.S. Congress, Office of Technology Assessment, *Energy Efficiency: Challenges and Opportunities for Electric Utilities*, OTA-E-561 (Washington, DC: U.S. Government Printing Office, September 1993), p. 41. PURPA, the Public Utility Holding Company Act, the Energy Policy Act, state law, and state public utility commissions impose numerous economic regulations regarding rate-setting, utility planning, competition, and other aspects of utility governance. These significantly influence the market for energy efficiency and alternative energy technologies.

[70] It is too early to measure the costs or effectiveness of these vehicle technology mandates. It is worth noting that these vehicle- and power-purchasing requirements do not mandate purchases of a particular narrow technology. Most of the requirements can be met through a variety of technical routes. One exception is the California zero emissions vehicle standard, which effectively mandates electric vehicles. Even here, however, a number of competing battery, recharging, and propulsion technologies vie for the prospective market. Another OTA assessment, "Advanced Automotive Technologies" (forthcoming), examines technological possibilities for future automobiles.

[71] For example, Sam Kazman, Competitive Enterprise Institute, presentation at "BioEast'95," Washington Hilton and Towers, Washington, DC, Jan. 10, 1995.

[72] For permitting barriers to innovative environmental technologies, see U.S. Environmental Protection Agency, op. cit., footnote 19.

[73] Dag Syrrist, Technology Funding, testimony before the Senate Committee on Environment and Public Works, May 21, 1993.

requirements. Some U.S. environmental, health, and safety regulations mandate the use of particular devices or methods (so-called technology- or design-based standards), though most regulations are theoretically performance-based (i.e., they establish a standard to be met, rather than a means for meeting the standard). However, even performance-based standards are frequently based on established reference technologies. In such cases, companies and regulators are likely to prefer reference technologies they are confident will meet standards, rather than innovative approaches that are less certain.

Many of these problems can be overcome with proper formulation, interpretation, and enforcement of regulations. In the environmental arena, several proposals and regulatory experiments have been implemented to simultaneously lower compliance costs, maintain or improve environmental performance, and improve the climate for technological innovation. Some of the approaches give companies flexibility to meet overall facility emissions and effluent requirements without requiring detailed permitting of each source at the facility. In New Jersey, for example, a pharmaceutical plant was recently issued a single permit in place of numerous individual air, water, and waste permits. In Minnesota, the state's environmental agency issued a flexible permit for certain air pollutants to a 3M plant in St. Paul. It allows the firm to modify processes without requiring repermitting if it gives the agency 10 days' advance notice and stays within facility-wide emissions limits.[74] Tradable pollution allowances, such as those authorized under the Clean Air Act Amendments of 1990 to govern sulfur dioxide emissions from power plants, also add regulatory flexibility and may lower compliance costs, although the effect on innovation is not yet clear. In the pharmaceutical arena, the FDA has proposed dropping preapproval requirements for certain changes in pharmaceutical production processes.[75] These and other related efforts do not directly promote markets for innovative technologies, but they may remove impediments to changes.

Another approach is to offer companies waivers that allow limited environmental noncompliance, or reduced penalties for noncompliance, when innovative technologies are tried or developed, but do not quite meet the mark.[76] Such "fail-soft" approaches would still need safeguards to ensure protection of public health and the environment, and to prevent abuse. Participation might be limited to firms with good compliance records, similar to the Occupational Health and Safety Administration's (OSHA's) Star program that allows eligible firms greater compliance flexibility.[77] Overall, such efforts could enable regulators to protect public safety and the environment, while encouraging technological innovation.

Government Procurement

Government procurement can also create markets for new technologies. Aircraft, integrated circuits, computers, satellites, biotechnology products, and some energy technologies all received significant boosts from government purchases. Such procurement can provide potential developers of new technology with sufficient assurances of a market to make it attractive for them to invest in production facilities. By acting as a launch customer, the government provides manufacturers with the early revenues, scale economies, experience, and user feedback they need to improve their products and make them affordable for commercial users. Early government use may also demonstrate the performance of new technology for

[74] U.S. Congress, Office of Technology Assessment, op. cit., footnote 18, p. 275.

[75] David J. Hanson, "Clinton Unveils Environmental and Pharmaceutical Regulation Reform," *Chemical and Engineering News,* vol. 73, No. 14, Apr. 3, 1995, pp. 15-16.

[76] U.S. Environmental Protection Agency, op. cit., footnote 19.

[77] U.S. Congress, Office of Technology Assessment, op. cit., footnote 18, p. 277.

potential commercial users, stimulating future demand. Nevertheless, there are limitations to relying on government procurement to commercialize new technologies to civilian markets.

Federal purchases were a major impetus for the commercialization of integrated circuits (ICs). Though integrated circuits were developed by private industry without government funding or direction, commercial firms were hesitant to use them because of their higher cost and uncertain long-term reliability. IBM, for example, opted to use “hybrid” integrated circuits—a stepping stone between discrete components and full integration—in its 360 series computers because existing vendors had not yet demonstrated an ability to manufacture ICs at the scale and quality IBM required.[78] The first uses of ICs were in the guidance system of NASA’s Apollo spacecraft and DOD’s Minuteman intercontinental ballistic missile systems.[79] Government users were willing to pay high prices for the miniaturized components because they provided a capability essential to the success of government missions.[80] These early government markets provided manufacturers with early incentives for investing in production facilities, and funded further improvement in IC capability and great decreases in cost. This led to a greatly expanding commercial IC market. During the decade from 1962 to 1972, the government share of the IC market dropped from 100 percent to one-third or less, while IC capabilities increased greatly and costs decreased (in current dollars) from $50 to a little more than $1 per IC.[81]

Military procurement has benefited other industries as well. Innovation in the aircraft industry was strongly influenced by military demand, although postal air mail contracts in the 1920s also provided a market. Commercial satellites, computers, and a host of other products are regarded as spin-offs of military and space efforts. Penicillin was first produced in large quantity for defense needs, although its initial development was not a military project. During World War II, the federal government bought all American production of penicillin at very high prices.[82] Although the market price for penicillin collapsed after the war, a firm foundation for innovation and commercial leadership in antibiotics and pharmaceuticals generally had emerged in the United States.

Civilian government procurement also has an impact. For instance, the National Institutes of Health (NIH) and other federal agencies support a market for biotechnology products, specialized reagents, and instruments to fill research needs. Such products are now sold to commercial researchers and for diagnostic and clinical use. In the case of alglucerase, an enzyme used for treating a rare genetic ailment called Gaucher disease, NIH procurement from an academic laboratory led to the creation of a biotechnology company that used the revenues and its increasing expertise

[78] Charles H. Ferguson and Charles R. Morris, *Computer Wars: How the West Can Win in a Post-IBM World* (New York, NY: Random House/ Times Books, 1993), pp. 8-9.

[79] Thomas R. Howell, Brent L. Bartlett, and Warren Davis, *Creating Advantage: Semiconductors and Government Industrial Policy in the 1990s* (Semiconductor Industry Association and Dewey Ballantine, 1992), pp. 25-26, fn. 35.

[80] A Philips executive is reported to have said: “This thing [a very early integrated circuit from Texas Instruments] only replaces two transistors and three resistors and costs $100. Aren’t they crazy!” See Ernest Braun and Stuart Macdonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics* (New York, NY: Cambridge University Press, 1978), p. 113.

[81] Ibid.

[82] Basil Archilladelis, “The Dynamics of Technological Innovation: The Sector of Antibacterial Medicines,” *Research Policy,* vol. 22, 1993, pp. 279-308. During the war, the federal government paid producers cost plus $20 per dose. When commercial sales were permitted in 1946, prices dropped to $1 per dose and, by 1949, to 10 cents.

to commercialize the drug.[83] Federal funding of academic institutions, as well as government laboratories, also promotes initial markets for high performance computers and scientific instruments that may then be adapted for commercial requirements.

The day-to-day operations of government—as a major user of energy, motor vehicles, buildings, office equipment, paper, and so on—also open up opportunities for using the government's buying power to facilitate new technology commercialization. As the federal government is the largest user of energy in the nation, a number of laws and Executive Orders have been promulgated since the mid-1970s to try to improve federal energy efficiency.[84] The most recent examples are the Energy Policy Act (EPACT) of 1992 and Executive Order 12902 on Energy Efficiency and Water Conservation in Federal Facilities. By serving as a testbed for innovative technologies, government facilities may reduce the federal government's energy bill and demonstrate performance for wider markets (though many of the cost-effective energy efficiency options are already commercially available[85]). Executive Order 12873 on Federal Acquisition, Recycling and Waste Prevention, which promotes federal purchases of environmentally preferable goods, may also stimulate markets for new technologies and products, though it is difficult to predict the effectiveness of such procurement standards in areas in which the federal government represents only a small portion of the market.

While the ability of government to pay a premium for products that meet defense and space program needs can be a springboard for commercial technology spin-offs, government market needs can also lead producers away from commercial markets. Military needs are often specialized or unique, and may not match civilian market demands. High technology military production often occurs at relatively low production rates and emphasizes product characteristics that have little commercial utility. Commercial producers, in contrast, usually look for frequent process improvements that allow lower cost, high-volume manufacturing. These and other differences between military and civilian needs suggest important limitations to relying on defense-related procurement, and more generally, defense-related technology transfer for spin-offs to the commercial sector.[86] Overreliance on specialized government markets has been implicated in the demise of some firms and technologies. For instance, Thinking Machines Corp., a developer of high-performance computer systems, was forced into bankruptcy reorganization at least in part because it concentrated its efforts on the needs of government clients instead of potential commercial users of scalable parallel computers.

Tax and Credit Provisions

Tax provisions, subsidized or facilitated tax credits, loan guarantees, and other subsidies also influence commercialization by channeling economic activities. Some provisions specifically target technological change, while others address broader economic activities (e.g., capital investment)[87] that indirectly provide incentives for new technologies. Such provisions may simultaneously serve a goal of stimulating new technology markets

[83] U.S. Congress, Office of Technology Assessment, *Federal and Private Roles in the Development and Provision of Alglucerase Therapy for Gaucher Disease*, OTA-BP-H-104 (Washington, DC: U.S. Government Printing Office, October 1992).

[84] U.S. Congress, Office of Technology Assessment, *Energy Efficiency in the Federal Government: Government By Good Example?* OTA-E-492 (Washington, DC: U.S. Government Printing Office, May 1991).

[85] Ibid., p. 3.

[86] Alic et al., op. cit., footnote 17, pp. 43-44.

[87] For instance, capital investment may be affected by tax rates on income and capital gains, by depreciation and amortization provision, and—in the past when they were in force—investment tax credits.

while assisting certain user industries, such as small business. For instance, the Japanese government and some quasi-public bodies have provided subsidized credit and leases since the 1980s to help small and medium-sized companies modernize. These measures also stimulated markets for advanced manufacturing technologies such as numerically controlled machine tools, robots, and computers.[88]

Tax provisions can interact with consumer preferences and other market factors to propel markets for certain technologies in some countries, while demand remains low in others. A case in point is the commercialization of electronic fuel injection (EFI) for automobiles (see box 3-6). Taxes on automobiles by engine displacement and high taxes on fuel were significant factors leading to earlier commercialization of EFI in Europe than in the United States. They also may have contributed to a foreign EFI supplier capturing the technological lead from an American innovator.

Tax and other provisions work on both the supply side and demand side of technology development, as exemplified by the research and experimentation tax credit on the one hand, and tax credits for purchase or use of particular types of technologies in certain industrial sectors on the other. The current tax code contains at least 17 provisions that may affect technological development through incentives for research, purchases of particular products, or investments in certain industries, not including general provisions such as tax rates and alternative minimum taxes (see table 3-7). Many of these provisions are related to energy and environmental technologies, reflecting the strong regulatory role the government maintains in these areas and the energy crisis of the 1970s, which placed a premium on developing alternative energy sources and reducing energy consumption. Only the research and experimentation tax credit is more widely applicable to U.S. industry.

Tax provisions that favor certain activities or industries are often considered market distortions that produce an inefficient allocation of resources; some tax provisions, however, correct for costs borne by those outside a particular market or by society as a whole, such as pollution costs or national security costs associated with high reliance on imported petroleum. Often such negative externalities are dealt with through regulations; in some cases, fiscal incentives in the form of taxes and tax breaks may yield results that are more cost-effective and promote innovation more than conventional regulatory approaches.[89] Fiscal incentives can allow firms to be more flexible in the means by which they meet standards and can give companies incentives to do better than standards require.

Tax credits or deductions can be costly to government. Every dollar of forgone tax income is equivalent to an additional dollar of expenditures. The investment tax credit cost between $13 billion and $37 billion each year between 1979 and its elimination in 1987. Accelerated cost recovery, which is still available for some classes of assets, cost as much as $64 billion in 1987.[90] Also, taxes forgone may or may not efficiently lead to desired innovation or investment. For instance, the investment tax credit stimulated between $0.12 to $0.80 in additional equipment investment for every dollar forgone by the Treasury, according to a number

[88] U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, March 1990), pp. 162-166.

[89] A discussion of this can be found in U.S. Congress, Office of Technology Assessment, op. cit., footnote 18, ch. 9; and another OTA assessment, *Environmental Policy Tools: A Users Guide* (forthcoming).

[90] Joint Committee on Taxation, Estimates of Federal Tax Expenditures, Fiscal Years, Annual.

BOX 3-6: Electronic Fuel Injection: Tax Provisions and Market Forces

Electronic fuel injection (EFI) for gasoline-powered automobile engines, while patented by a U.S. firm, was commercialized more quickly in Europe. To some extent, institutional factors were responsible. In the vertically integrated U.S. auto firms, carburetor divisions resisted EFI because it would make their technology obsolete; European auto manufacturers, on the other hand, outsourced carburetors and could readily switch to EFI. For the most part, however, the faster commercialization in Europe resulted from more favorable market conditions.

U.S. and European firms developed mechanical fuel injection first for airplanes and then for racing cars. Users were willing to accept the fuel injectors' high cost and weight because they provided engine power critical to their missions. Bendix Corp. patented the first EFI system for automotive use in 1961, having transferred the technology from its aerospace division to its automotive division.

While EFI promised several advantages over carburetor technology in automotive applications—smaller size, improved performance (faster acceleration), improved fuel efficiency, and reduced exhaust emissions—these attributes were not valued highly by either manufacturers or drivers in the United States. Most drivers were content to purchase larger cars with larger engines in order to get improved performance; interest in fuel efficiency did not grow until the oil shocks of 1974 and 1979 and the imposition of CAFE (corporate average fuel efficiency) standards in 1975. Though the U.S. Environmental Protection Agency (EPA) promulgated emission regulations in 1970, they could be easily met by adding electronic controls to carbureted engines. Only in the mid-1980s—when European and Japanese manufacturers demonstrated that properly designed and tuned EFI systems could meet more stringent fuel economy and emissions standards, while improving performance without Increasing manufacturing costs---did EFI become popular in the United States.

EFI achieved earlier success overseas because of differences in market demand. European drivers typically valued performance and handling more than American drivers, and saw the benefit of extracting greater power from a smaller engine. This tendency was reinforced by taxes assessed on vehicles in proportion to engine displacement in Europe during the 1960s and 1970s. Higher gasoline taxes in Europe also gave drivers an incentive to seek improved fuel economy even without government regulation. Bosch GmbH, a German auto parts supplier, licensed EFI from Bendix in 1967, and began supplying the technology to Volkswagen in 1968 (and later to other European manufacturers). By the time U.S. consumers demanded EFI in their vehicles, Bosch was well positioned to capture a large share of the global market.

SOURCE: Kevin Beaty, "Electronic Fuel Injection, " unpublished contractor report prepared for the Office of Technology Assessment, U S Congress, Washington, DC, June 1995

of estimates.[91] Increased income and tax revenues resulting from the additional capital investment are less certain.

Inadequate design of tax provisions can limit their effectiveness in achieving a desired policy goal. For example, federal tax credits for residential investments in renewable energy and energy efficiency between 1977 and 1985 were limited to add-on equipment such as weather-stripping, storm windows, and solar water heaters. Certain energy-efficient and solar features integrated into building architecture to serve both energy and

[91] Joseph J. Cordes, "The Effect of Tax Policy on the Creation of New Technical Knowledge: An Assessment of the Evidence," in Richard M. Cyert and David C. Mowery (eds.), *The Impact of Technological Change on Employment and Economic Growth* (Cambridge, MA: Ballinger, 1988), and Robert Chirinko and Robert Eisner, "Tax Policy and Investment in Major U.S. Macroeconomic Models, ''*Journal of Public -Economics.* March 1983.

TABLE 3-7: Tax Code Provisions for New Products and Technologies

U.S. Code Annotated, title 26, section(s):	Section title and description
23	*Resident/a/Energy Credit (repealed Nov. 5, 1990 by Public Law* 101-508)—provided nonrefundable credits of 15% for energy conservation and 40% for renewable energy for qualified residential investments,
28	*Clinical Testing Expenses for Certain Drugs for Rare Diseases or Conditions*—nonrefundable 50% credit for clinical testing expenses for orphan drugs; such expenses cannot be applied to research tax credit (section 41) simultaneously, although it counts toward base expenses,
29	*Credit for Producing Fuel from a Nonconventional/ Source—$3* per barrel of oil equivalent credit adjusted for Inflation and real 011 prices for certain unconventional oil and gas production; repealed for certain biomass energy; credit reduced by value of other federal, state, or local credits, grants, subsidies, and tax-free bonds,
30	*Credit for Qualified Electric Vehicles*---- 10% of cost, up to $4,000 per vehicle put in service, credit phases down during years 2002 to 2004.
40	*Alcohol Used as Fuel*— $0.60 refundable credit per gallon for alcohol used as or in fuel; $0,45 per gallon for 150-190 proof alcohol; an additional $0.10 per gallon for qualified small producers; terminates Dec. 31,2000,
41	*Credit for Increasing Research Activities*-----20% refundable credit on qualified research and experimentation expenses above a base amount (this credit has required annual renewal).
43	*Enhanced Oil Recovery Credit*—-- 15%. refundable credit on qualified enhanced (tertiary recovery) 011 recovery costs; phased down as real oil price increases,
45	*Electricity Produced From Certain Renewable Resources*—$0.015 per kilowatt hour for electricity generated by wind or closed-loop biomass systems; credit good for the first 10 years of a facility built before July 1, 1999; phased down with real electricity price increases; credit reduced by value of other government credits, grants, subsidies, tax-free bonds.[a]
48(a)	*Energy Credit*— 10% credit on portion of energy facility for certain solar heat, hot water, cooling, electric and geothermal electric investments; credit reduced by value of other government credits, grants, subsidies, tax-free bonds
136	*Energy Conservation Subsidies Provided by Public Utilities* - deductions for utility subsidies for purchase and Installation of listed industrial, commercial, and residential energy conservation equipment; 100% for residential equipment, for nonresidential equipment, 40% in 1995, 50% in 1996, 65% thereafter
174	*Research and Experimental Expenditures*— such expenditures can be treated as deductible expenses
179A	*Deduction for Clean-Fuel Vehicles and Certain Refueling Properties*----up to $2,000 per car, $5,000 per medium truck, $50,000 for heavy trucks and buses; deductible for acquisition or retrofit to run on certain alternative fuels other than electricity; deduction phases down *25%* in 2002, 50% in 2003, 75% in 2004; up to $100,000 deductible per location for alternative fuel refueling and electric vehicle recharging facilities,
193	*Tertiary Injectants*— deduction for certain materials injected for tertiary oil recovery
611, 612, 613, 613A	*Depletion allowances* for mines, oil and gas wells, other natural deposits, and timber.
616, 617	*Deductibility of certain development and mining exploration expenses.*
4041	*Lower taxes for alcohol fuels relative to gasoline and diesel fuel.*
4064	*Gas Guzzler Tax*— schedule of excise taxes on automobiles rated at fewer than 22.5 miles per gallon; tax Increases from $1,000 to $7,700 as fuel economy decreases,
4681, 4682	*Tax on Ozone-Depleting Chemicals*--- taxes on ozone depleting chemicals phased out under *law.*

[a] The Energy Policy Act of 1992 (Public Law 102-486), Section 1212, provides for the Department of Energy to pay $0.015 per kilowatt hour for qualified renewable electricity production for the first 10 years of production.

NOTE: This list is not necessarily complete. Other general provisions of the tax code and Alternate Minimum Tax provisions may affect new technology markets. Some of the provisions listed above directly affect incentives for research and development, rather than the purchase of new technologies.

SOURCE: Office of Technology Assessment, 1995.

structural purposes were disallowed by the Internal Revenue Service (IRS)—even though integrated features were a more efficient means to achieve national energy goals.[92] Also, credits were offered on the basis of dollars spent on certain technologies, rather than on the performance (amount of energy saved) of those technologies. Even if Congress and the IRS considered these issues at the time residential energy credits were in force, it might still have been difficult for the IRS to decide whether or not a window should be considered a passive solar energy collection device and to determine the actual energy savings resulting from residential energy investments.

Other Market Incentives

Purchase commitments, bounties, and other incentives from potential users of a new technology can also speed commercialization. Such approaches may allow the private sector alone, or with some government support, to help bridge the gaps between R&D, manufacturing, and initial sales, while ameliorating risks for developers and earliest users. Several examples from the energy technology arena follow:

1) Following successful field demonstrations of gas-fired residential heat pumps, a consortium of gas utilities provided $14 million in incentives for the first three years' sales of the devices.[93] In return for the support of utility companies, the manufacturer will begin reimbursing utilities after the 50,000th unit is sold. The manufacturer benefits from promotion of the new technology by the gas utilities, who then benefit by being better able to compete with electric utilities. Early customers benefit from a utility subsidy, as well as any advantages the technology may offer over rival options.
2) Electric utilities took the lead in offering a $30 million bounty—termed a *golden carrot*—to manufacturers for developing and commercializing high-efficiency refrigerators that did not use chlorofluorocarbons as their coolant.[94] The winning manufacturer, Whirlpool, collects the reward as it markets the award-winning models in the service areas of the 24 participating utilities. Golden carrot competitions are planned for other appliances as well.
3) Energy utilities are also participating in innovative commercialization approaches for new power generation technologies. The Fuel Cell Commercialization Group (FCCG) links gas and electric utilities in the United States and Canada as a buyer's group.[95] FCCG members, a fuel cell manufacturer chosen by FCCG on the basis of a winning development and commercialization proposal, the Electric Power Research Institute, and DOE participate in technology development, demonstrations, exchange of information, and the establishment of project milestones. As an incentive to buy early demonstration and commercial units, manufacturers have agreed to pay FCCG members royalties on later sales. This arrangement helps defray the risks of early participation. The manufacturer agrees to meet certain cost and technical criteria before receiving payment from FCCG buyers.
4) The Utility PhotoVoltaic Group (UPVG) and the Utility Biomass Energy Commercialization Association (UBECA) are other utility-led efforts to move technologies out of the

[92] For instance, 26 CFR Part 1 Sec. 1.23-2(e)(3) disallows dual-use features such as windows and greenhouses as "solar energy properties" within the meaning of the tax provision.

[93] Howard Geller and Steven Nadel, "Market Transformation Strategies To Promote End-Use Efficiency," *Annual Review of Energy and Environment*, vol. 19, 1994, pp. 301-346.

[94] Ibid.

[95] Fuel Cell Commercialization Group, *FCCG Update*, vol. 5, No. 1, spring 1994.

laboratory and into the market by involving potential buyers in late development, demonstration, and early purchases.[96] UPVG plans to catalyze early sales of photovoltaic systems by sharing technical information with potential users, aggregating purchases for some small-scale applications, and proposing private-public cost-shared projects that can lead to wider, higher volume commercial markets.

Buyers' commitments to precommercial technologies do not guarantee successful commercialization. In the 1960s, U.S. airlines committed $60 million to develop the supersonic transport (SST), in partnership with airframe and engine manufacturers and the federal government (which spent nearly $920 million over about a decade).[97] At its peak in 1967, airlines reserved 129 delivery positions for the SST—most required $200,000 refundable deposits, although the last 16 positions required nonrefundable $750,000 payments. The SST project failed to meet technological and commercial goals and faced high cost overruns; nevertheless, the government did not terminate the program. The government continued to fund development of the SST despite industry's resistance to providing matching funds of 25 percent in 1963 and the lowering of the private cost-share requirements to 10 percent in 1967. In contrast, most recent U.S. public-private cost-shared technology programs have featured 50 percent or greater private shares.

The energy utility sector appears prominently in this discussion on commercialization incentives not because utility managers are necessarily more imaginative than executives in other sectors, but because energy utilities are highly regulated entities (financial as well as environment, health, and safety regulations) in which numerous technological, institutional, regulatory, and tax provision changes have recently or are currently taking place. In many states, public utility commissions have made changes in utility governance that make conserving energy an attractive alternative to increasing production capacity. In some cases, utilities are allowed to earn a financial return on energy saved; a number of other utilities are finding that increasing capacity can be costly, lengthy, and uncertain due to both regulatory requirements and the resistance of local residents to new facilities. Also, the federal tax code allows utilities to deduct certain energy-efficient subsidies provided to customers (26 U.S.C. 136). These circumstances have allowed or encouraged utilities to prime markets for new energy-efficient technologies through rebates, bounties, technical assistance, and bulk buying. Although energy utilities operate under conditions different from other industries, there may be opportunities for nontraditional commercialization approaches in other industries as well.

CONCLUSION

Successful innovation and commercialization depend on far more than a strong science and technology base. Commercialization is a business decision based on reasoned judgments about future returns from investments in product design and development, manufacturing, marketing, and distribution. The size of these returns—and hence the incentives for firms to commercialize new technology—depends on a number of factors beyond the boundaries of individual firms. The availability of capital, the size and nature of markets, and the existence of complementary assets all influence the ability of firms to commercialize new technologies. Firms often have little control over these factors, or little incentive to adapt them to their needs. The effort required is often too extensive and the benefits are often too diffuse for

[96] Utility PhotoVoltaic Group, "The TEAM-UP Request for Proposals," fact sheet; Utility Biomass Energy Commercialization Group, *Biomass Bulletin*, vol. 1, No. 1, autumn 1994.

[97] Susan A. Edelman, "The American Supersonic Transport," in Linda R. Cohen and Roger G. Noll (eds.), *The Technology Pork Barrel* (Washington, DC: The Brookings Institution, 1991), ch. 6, pp. 97-147.

any one firm to capture. Attempts to improve U.S. capabilities in commercializing emerging technologies must recognize both the importance of such factors and the need for new forms of interaction among industry, government, and universities to address them.