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Bangalore: India's Emerging Technopolis

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This chapter describes and analyzes the growth of high-tech microelectronics industries in Bangalore, an emerging technopolis that often is referred to as "India's Silicon Valley." The context of technology transfer in Bangalore's (and, more generally, India's) R&D organizations and private industries is analyzed,

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AUTHORS' NOTE: The present chapter is based on research visits to Bangalore to analyze the growth of high technology industries. Interviews were conducted with 70 officials involved in Bangalore's high-tech development, including officials from the central and state government, academic institutions, R&D institutes, private industry, financial institutions (venture capital firms), and electronics entrepreneurs (Singhal & Rogers, 1989b; Singhal, 1989). This chapter also benefits from interviews with managers, scientists, and officials of Texas Instruments, the Indian Consulate in San Francisco, California, the Silicon Valley Indian Professionals Association, and more than 30 other high-tech companies in the Silicon Valley and Orange County area. The research was funded by the Annenberg School for Communication, University of Southern California, and the University Research Institute at the University of Texas at Austin.

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Bangalore: India's Silicon Valley

Several Third World countries—such as Singapore, South Korea, Taiwan, Hong Kong, Brazil, Mexico, Egypt, and India—are attempting to create indigenous high-technology microelectronics industries.[1] Microelectronics, that part of the electronics industry centering on semiconductor chips and their applications (such as in computers and telecommunications), usually is considered the highest of high technology. Some enthusiastic observers claim that microelectronics potentially represents a type of industry that can allow Third World nations to leapfrog the industrial era to become information societies (Singhal & Rogers, 1989a).

The government policies of former Indian Prime Minister Rajiv Gandhi, an airplane pilot and a technophile, promoted indigenous businesses in microelectronics, telecommunications, computers, and computer software. In five years (1984-1989), the number of computers in India increased fifteenfold, computer software exports increased eightfold, and the computer industry's revenues increased fivefold (Singhal & Rogers, 1989b).

Bangalore, the capital of the state of Karnataka in southern India, is the nation's fastest-growing city (8% annually) with a population of four million people in 1989 (Figure 12.1).[2] Large and small microelectronics-based industries increasingly are agglomerating in Bangalore. *Agglomeration* is the degree to which some quality is concentrated spatially in one area (Rogers & Chen, 1988). In 1989, Bangalore housed 375 large and medium-scale industries, of which 135 (36%) were

Figure 12.1. Location of Bangalore in the Interior of India's Southern Peninsula

electronics companies (Vyasulu, 1987). In addition, more than 2,600 small-scale electronics companies operated in the area (Matthai, 1987).[3] In 1989, Bangalore's eight large industrial parks (including the Peenya Industrial Estate, the largest in India) housed an estimated 3,000 companies engaged in electronics manufacturing or assembly, a number steadily growing at the present time. Bangalore's 3,000 large, medium, and small-scale electronics companies employed an estimated 100,000 people, registering sales of $1.2 billion (U.S.) in 1989 (Varma, 1989).[4]

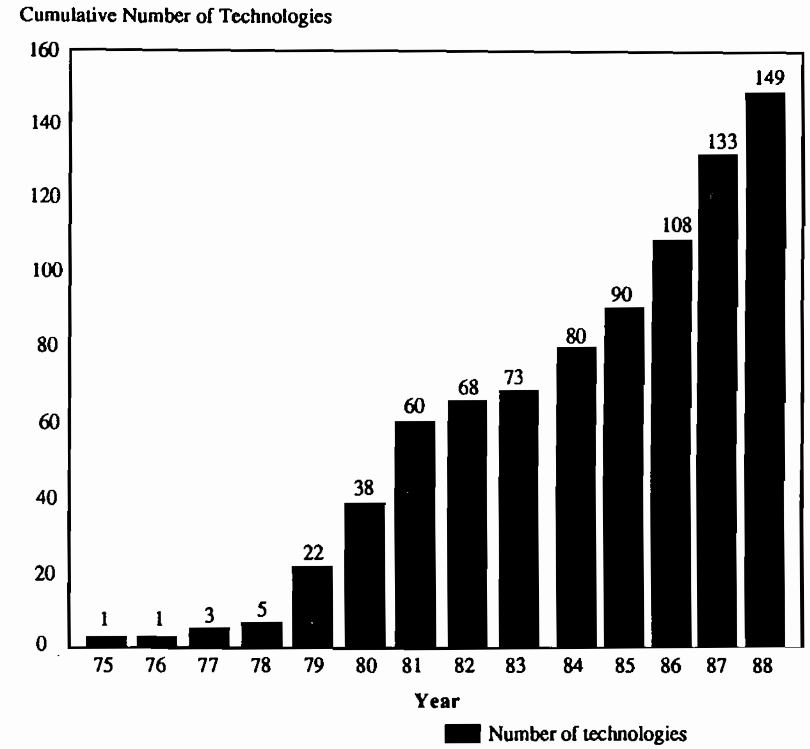

Figure 12.2. Technologies Transferred from ISRO to Indian Industries

SOURCE: Indian Space Research Organization (1989).

Technology Transfer in Bangalore

Bangalore's high-tech R&D organizations conduct both basic and applied research. Although several of Bangalore's R&D organizations actively transfer technological innovation (developed in their laboratories) to private industry, others are relatively slow.

ISRO: A Technology Transfer Success Story

The Indian Space Research Organization (ISRO), headquartered in Bangalore, has a spectacular record in transferring technological innovation to Indian industries. A Technology Transfer Center was established at ISRO in 1982 and by early 1989 ISRO had transferred technical know-how for 160 products and processes to private industry (Figure 12.2), and technology transfer arrangements for another 150 technological innovations were in progress (Indian Space Research Organizations, 1989).

ISRO's technology transfer activities are highly profitable: In 1988-1989, ISRO transferred technical know-how worth $100 million dollars to Indian industries, earning 50% of its annual budget. ISRO has transferred technological innovation to industry in high-precision optics, microelectronics, adhesives, ceramics, computer software, and television hardware (Nilekani, 1988). Several Bangalore-based entrepreneurs started new high-technology companies centered around ISRO's technological innovations. Although many of ISRO's technology transfer arrangements have spurred high-tech activity in Bangalore, created jobs and wealth, and led to import substitution, relatively few have found big commercial markets.

IISc's Center for Scientific and Industrial Consultancy

The Indian Institute of Science (IISc) is Bangalore's (and India's) premier research university, excelling in high-technology areas such as electrical engineering, computer science, material science, aeronautical engineering, and biotechnology. Established in 1909 (by visionaries such as J. N. Tata and Maharaja Wodeyar IV), IISc in 1989 had 30 scientific departments and centers, 400 faculty members, and 1,400 students. During the past 80 years, IISc has trained several thousand scientists and engineers, many presently employed in Bangalore's high-technology industries. Several of IISc's faculty and alumni (like Dr. C. V. Raman, Dr. Homi Bhabha, and Dr. Vikram Sarabhai) helped found many of Bangalore's scientific institutions and R&D labs.

Through the Indian Institute of Science's Center for Scientific and Industrial Consultancy (CSIC)—established in 1973—industry-sponsored R&D is undertaken, and technological innovations developed in IISc's labs are transferred to Bangalore's private industries. By 1989, more than 2,000 projects (ranging from one-day consultancy projects to complete technology transfer arrangements) were completed by CSIC. By 1989, 180 (40%) of IISc's 450 faculty members had participated in CSIC-industry projects. IISc faculty are allowed to consult with industry the equivalent of one workday per week and retain 50%

of the consultation fee; the remaining 50% goes to IISc. IISc's policies on faculty consulting are relatively liberal compared to other scientific institutions in India, an important reason for CSIC's success.

CSIC has been proposed as a model center for academic-industry collaboration, especially for the five Indian Institutes of Technologies (IITs), which are excellent teaching universities but are low in research output and have weak links to industry (Singhal & Rogers, 1989b). Although IISc is understandably proud of its excellence in research, several factors limit the impact of IISc's technology transfer activities. Most research conducted at IISc is basic, as opposed to applied research. Also, IISc's CSIC has maintained a somewhat low profile in Bangalore. In 1988-1989, CSIC received 350 project proposals, of which only 150 were undertaken (Subramanya, 1988). Furthermore, CSIC is understaffed severely for its wide-ranging activities. Ways to boost applied research at IISc while maintaining ongoing basic research and further strengthen the IISc-industry interface are being explored.

C-DOT: A Model R&D Organization

In 1984, Satyan ("Sam") Pitroda, an overseas-returned Indian (formerly an executive of Rockwell, Inc., in Chicago, and holder of 50 patents in telecommunications equipment), founded the Center for Development of Telematics (C-DOT) headquartered in Bangalore and New Delhi. C-DOT represents an organizational model for Indian R&D institutes: It conducts state-of-the-art R&D to meet Indian's specific telecommunication needs; is functionally autonomous from the government; has a dynamic leader in Sam Pitroda, a flat hierarchical structure, and highly motivated goal-oriented scientists and engineers; and it transfers technological innovations (developed in its labs) to private industry (Singhal & Rogers, 1989b).

C-DOT developed state-of-the-art telephone switching equipment to serve India's special telecommunications needs, which are high traffic and low density (as compared to low traffic and high density in most Western countries) and extreme temperature and humidity conditions. C-DOT successfully developed the technology for (1) electronic PABX systems, (2) a 128-line rural automatic exchange (RAX), and (3) 4,000-line and 10,000-line main automatic exchanges (MAXs). In 1986, C-DOT's EPABX technology was transferred to 42 private vendors, several of which established manufacturing operations in Bangalore (for example, Unitel Limited). In 1988, C-DOT's RAX technology was transferred to Indian Telephone Industries (ITI), and production of RAXs began in a C-DOT–ITI plant located in Bangalore's Electronics City.

Ancillaries and Technology Transfer

Bangalore is home to six large public sector companies, of which several conduct high-tech defense-related work: (1) Indian Telephone Industries (manufacturer of telecommunications equipment, electronic exchanges, and integrated circuits); (2) Bharat Electronics Limited (a government defense contractor); (3) Hindustan Aeronautics Limited (HAL) which began during World War II as a repair/maintenance center for Allied fighter planes, and presently produces supersonic MIG aircraft; (4) Hindustan Machine Tools (HMT), producer of state-of-the-art machine tools and precision watches; (5) Bharat Heavy Electricals Limited (HBEL); and (6) Bharat Earth Movers Limited (BEML), which spun off from HAL in 1964. Encouraged by the government's industrial policy of self-reliance, some 130 ancillary companies have been established by ITI (48), BEL (22), HAL (10), and HMT (50), most of which are agglomerated in Bangalore (Rao, 1987).

The ancilliary industries represent a potential conduit to transfer technology from the large public sector companies to the commercial marketplace. The ancilliary industries in Bangalore, however, are generally captive suppliers to one or few of these large public-sector companies, thus reducing the market potential of their products. Although the large public-sector company buys the ancilliaries' products, the transferred technological know-how (of producing these products) does not get commercialized and introduced into the marketplace.

Understandably, Bangalore's small companies (ancilliaries included) fare worse when it comes to international technology transfer. Quite often the resources that are required to span vast distances are limited. Only large high-tech companies have the staying power and resources to risk overseas ventures. Even in the case of computer software, small companies lack start-up capital, market research, and the staying power to compete with bigger companies.

Critical Mass, Venture Capital, and Technology Transfer

Agglomeration of high-tech firms in a technopolis is important because it concentrates a critical mass of successful entrepreneurs, who

then support and reinforce each other in the uncertain situation of launching new companies. The concept of a critical mass comes from nuclear physics, where it refers to the minimum amount of radiation needed to set off a chain reaction (Rogers & Larsen, 1984). In nuclear physics a chain reaction is set off only when fissionable materials of a certain grade of purity are brought together. Impurities, if present, dampen the interaction between fissionable particles and thereby prevent a chain reaction.

In Bangalore, the level of interaction between co-present elements of the critical mass is not very active in transferring technology between R&D establishments and private industry. Because such interaction is essential for Bangalore's further development as a technopolis, ways to enhance a self-sustaining chain reaction of technology transfer must be found. Bangalore's high-tech environment can be enhanced by such efforts as infrastructure development (for example, an improved local telephone service), government support (for example, tax incentives for high-tech firms), and financing of entrepreneurship (for example, the presence of venture capital). For balanced, coordinated high-tech growth, cross-institutional cooperation is necessary (Smilor, Gibson, & Kozmetsky, 1989).

The role of venture capital is crucially important in fueling high-tech growth (leading to a "chain reaction") in a technopolis (Rogers & Larsen, 1984; Segal, Quince, & Wicksteed, 1985; Singhal & Rogers, 1989b). Most entrepreneurs are technologists, not businessmen, and so the venture-capital firm makes an important contribution to the entrepreneurial start-up by providing managerial advice to the entrepreneur. Most Indian technologists (also true in Bangalore) come from middle-class families which, although highly educated, normally do not have access to large amounts of private capital. The main source available to an entrepreneurially driven engineer are banks, which are usually resistant to funding high-tech start-ups.

Until 1988, venture capital for high-tech start-ups was virtually nonexistent in Bangalore. In 1988, India's first private venture-capital company, Technology Development and Information Company of India (TDICI), established its headquarters in Bangalore. TDICI's president, P. Sudarshan, served earlier as chairman of ISRO's Technology Transfer Center in Bangalore. In 1989, TDICI invested $13 million (U.S.) in 40 high-technology ventures, with several located in Bangalore (Staff, 1989). In 1990, TDICI appraised another 90 high-technology ventures, representing a capital investment of $31 million (U.S.).

Although venture capital is a recent phenomenon in Bangalore, it is gaining momentum thanks to TDICI, Karnataka State Industrial and Investment Development Corporation (KSIIDC), and Karnataka State Financial Corporation (KSFC), two state-level financial institutions. KSIIDC and KSFC invest in large, medium, and small-scale industries (including several high-tech ventures), often as equity partners, and provide technomanagerial support for start-ups. KSIIDC (in cooperation with the Department of Electronics, New Delhi) has established a computer software park in Bangalore.

Reverse Technology Transfer: The Case of UNIX

In the past decades, most international technology transfer has been one-way—from Western industrialized countries to the Third World. The transfer of UNIX know-how from India to Western countries (primarily the United States) represents a spectacular case of technology transfer in the reverse direction.

After the exit of IBM from India in 1978 for refusing to allow more than 50% Indian ownership, the government of India evaluated various standards for the indigenous computer industry and decided on UNIX because of its nonproprietary nature. Although Western computer companies used UNIX mainly for educational and scientific purposes, Indian engineers developed UNIX for more wide-ranging commercial applications. Subsequently, as UNIX became more popular worldwide, Indian engineers with expertise on UNIX became highly sought. Several Indian firms with UNIX expertise are based in Bangalore, and many have secured UNIX export contracts from U.S. companies. Hindustan Computers Limited (HCL), India's largest computer manufacturer and a leader in UNIX, established a Silicon Valley-based subsidiary (HCL, America) that conducts UNIX-based R&D in India and subsequent manufacturing in the United States. HCL, America is one Indian company—among many others—that is a leader in reverse technology transfer.

Texas Instruments: A Case Study of Two-Way International Technology Transfer

The rapid growth of the computer industry has led to an acute shortage of software engineers worldwide. India, with 3 million scientists

and engineers, is uniquely placed to capitalize in the worldwide computer software markets. Furthermore, Indian engineers fluent in English are available at one-tenth of the cost of comparable talent in Western industrialized countries. Although India's initial response to global software opportunities was to export engineers (to work at clients' facilities overseas, primarily in the United States), currently India is exporting software products and services in addition to skilled workers and scientists.

One apparently successful strategy for boosting India's domestic computer software industry has been to use telecommunications links to access foreign markets. In pioneering such an effort, Texas Instruments (TI) established a software development center at Bangalore that is linked via a dedicated satellite to its Dallas headquarters.

When G. R. Mohan Rao—a vice president of TI and an expatriate Indian—accompanied TI's president to India in 1983, both were impressed favorably by the high caliber and low cost of Indian engineers, the attractive climate of Bangalore, and the political situation in New Delhi that favored high-tech development. In an innovative and bold move, TI decided to establish a software design facility in Bangalore. Government approval was secured in 1985. In 1990, TI employed 120 Indian engineers (mainly from IISc, IITs, and Bangalore's engineering colleges). TI engineers in India are paid a starting salary of about $250 (U.S.) a month, reasonable by domestic standards, but only about one-tenth of what TI would pay equivalent employees in the United States.

TI's software facility in Bangalore represents an investment of $5 million (U.S.) and is 100% U.S.-owned. In return, the Indian government requires TI's Indian business operations to be 100% export-oriented: In return for every dollar of foreign exchange earned, the Indian government allows TI to import into India (without any customs duty) sophisticated computer hardware and software packages of value equal to the exports. TI Bangalore researchers carry out computer-aided design of VLSI circuits; the research process is linked to TI Dallas by satellite, which transmits the software code.

India is trading brainpower for TI's technology in what appears to be a unique case of two-way international technology transfer, representing a win-win situation for both parties. TI has gained a foothold in India; Indian engineers have a foothold in TI; India is retaining its talent and getting it trained at TI's expense; the Indian government earns foreign exchange; and TI's Indian engineers are happy, learning state-of-the-art VLSI design in a pleasant work environment.

Software development in India goes beyond maintenance of "software factories" or "sweatshops" where labor-intensive work such as data entry, porting operations, digitalization of drawings, and typesetting are conducted. Although such business is welcome in India, more lucrative opportunities lie in software development work. Only about 30% of TI's Bangalore operations comprises routine work; 70% is developmental. Such developmental effort is not directed toward new data base concepts or new operating system designs but rather toward developing research ideas into prototypes, a high-risk venture with no guarantee of success. Because of India's lower operating costs, the financial risk in development projects is reduced drastically. India is thus an excellent site for development of "wish lists" or "zero budget" projects. For example, Indian programmers took 35 man-years to develop Instaplan, a highly successful computer software product, at about one-tenth the cost of what the project would have cost in the United States.

India offers several other advantages to TI: Indian maintenance of hardware has been better than expected; Indian workers have adapted easily to TI's work culture; the Indian government has been responsive to TI's needs; and time differences between TI India and TI Dallas permit continuous work around the clock.

TI has also found, however, that satellite communication does not substitute entirely for face-to-face interaction, especially when developing complex computer software codes. The success of such long-distance R&D depends much on the initiative and caliber of TI's Bangalore engineers. TI has overcome the distance barrier partially with the combination of an egalitarian work culture (which encourages individual initiative) coupled with the high-quality training and self-motivation of Indian engineers. The success of TI's pioneering effort has inspired other similar ventures. For example, plans are underway to establish a satellite link between Route 128 companies in Massachusetts and a software development park near Pune, India. The Japanese are planning a satellite-linked software development park near Nagpur in central India. And other U.S. high-tech firms, such as Hewlett-Packard and Digital Equipment Corporation (DEC), have followed TI to Bangalore.

Technology Transfer by Employee Attrition

When Texas Instruments sought approval to establish operations in India, the government of India stipulated that TI not recruit engineers

already working in the Indian computer industry. The government feared that TI's higher salaries would siphon off the brightest engineers from Indian computer companies. To allay such fears, TI hired only recent engineering graduates from Indian universities and research institutes. These initially hired employees were sent to Dallas, Texas, and Bedford, UK (where TI has another software facility), for advanced training. They have since become the core for TI's India operations, and subsequent recruits have been trained in India.

Several Indian engineers (about 10%) have left TI to work for other Indian computer companies, and a few have even spun off their own computer software companies. The company expects more engineers to leave in the future. A director of TI's Indian operations stated: "With the passage of time, the attrition of our technical staff will make a general contribution to the transfer of technical know-how to Indian industry." Our discussions at TI, Bangalore, showed that family ties provided an important impetus for engineers to leave TI. Engineers from all over India join TI for outstanding professional opportunities, a pleasant work environment, and good remuneration. But soon, family "pull" leads them to find jobs in their home cities. Thus, through employee attrition TI technology and training is transferred into the Indian high-tech industry.

Technology Transfer by Technological Presence

Another form of technology transfer from TI's Bangalore operation occurs when TI's sophisticated computer workstations are serviced locally in India. For example, TI's Apollo workstations are serviced by Hindustan Computers Limited (HCL), India's largest computer company. By servicing TI's equipment, HCL acquired maintenance expertise and familiarity with the state-of-the-art Apollo workstation. In fact, beginning in 1989, HCL started manufacturing Apollo workstations in India.

Bangalore: A Regional Economy with Global Ties

The case of Texas Instruments in Bangalore illustrates that high-tech areas in developing countries more often are integrated into global markets than the national economy. Many of Bangalore's emerging high-tech companies are integrated more into overseas markets than into the national or even the regional economy (Gollub et al., 1988). This globalization is particularly true for Bangalore's software companies. In this sense, Bangalore is "a foreign land within India."

Should the policies of the Karnataka state government (headquartered in Bangalore) facilitate further concentration of resources within Bangalore, making it a high-tech island with links primarily with global markets? In India, such a scenario not only is difficult to justify politically, but also raises important questions of regional socioeconomic inequality (Rogers & Sawhney, 1989). Another strategy would be to allow further concentration of resources in Bangalore, but at the same time encourage better economic and technological links with the hinterland. More developed domestic linkages would further diffuse the economic gains arising from Bangalore.

The infrastructure to enhance domestic and international communication is vital to reap benefits from regional economic development (such as that occurring in Bangalore). The Indian government has created NICNET (National Information Center Network), a versatile computer network, which makes electronic information transfer within and among 439 administrative districts. NICNET also will have nodes in Boston, Washington, D.C., and in Silicon Valley. The government is aiding linkages between Indian entrepreneurs by connecting major cities through Telecommunication Research Centers' packet-switching network, and is providing access to international telecommunications networks through the Indian National Satellite (INSAT).

Unsuccessful Technology Transfer: The Case of LCDs

For every successful technology transfer effort between Bangalore's R&D institutes and private industry, there exist many failures. One such failure (which proved to be a costly one) was the Indian-based attempt to transfer liquid-crystal display (LCD) technology from the Raman Research Institute (RRI) in Bangalore to Bharat Electronics (BEL), also headquartered in Bangalore.

In 1975, Dr. Chandrashekar perfected the LCD technology in his RRI lab in Bangalore. Although Japanese and U.S. scientists were close on Chandrashekar's heels in developing this technology, commercial worldwide exploitation of the LCD (in pocket calculators, watches, etc.) was yet to begin. RRI transferred its technical know-how to BEL, which in turn produced several prototypes of LCD watches, displaying

the tremendous commercial potential of RRI's technology. For five years (between 1976 and 1981) BEL pleaded with India's central government in New Delhi to approve a large LCD manufacturing plant, but the New Delhi bureaucrats provided no leadership. Meanwhile, Japan and the United States were quick to commercialize LCDs, reaping several billion dollars worth of sales a year. In 1984, the Indian government approved a technology transfer arrangement between Hitachi of Japan and Semiconductors Complex Limited (India) to produce LCDs, completely overriding the indigenous LCD know-how that had existed at RRI.

Integrated Technology Transfer: U.S. AID Center for Technology Development

Since 1987, the New Delhi office of the U.S. Agency for International Development (AID) has initiated programs to strengthen the market-driven R&D needs of Bangalore's industries, focusing especially on such high-technology industries as microelectronics, telecommunications, computers, software, and biotechnology (Gollub et al., 1988). U.S. AID's interest to boost high-technology industries in Bangalore was heightened during 1987-1988, when AID successfully implemented two technology-development programs in India: PACT (Program for the Advancement of Commercial Technology) and PACER (Program for the Acceleration of Commercial Energy).

With input from the Karnataka state government, the Indian Institute of Science, Bangalore's R&D institutes, TDICI (the venture-capital company), and private industries, U.S. AID is establishing a Center for Technology Development (CTD) in Bangalore to strengthen technology transfer between R&D centers and industry, and the subsequent commercialization of technological innovations (Arthur D. Little, Inc., 1987).

The idea of CTD grew out of a recommendation by *Karnataka in Transformation*, an AID-sponsored study, which observed that:

> A buyer-supplier initiative extends the chain of technology down from the second-generation level to the first-generation level. Applied technology may make Karnataka firms more innovative and able to compete, but moving the technology they are using to the supplier is equally essential. (Gollub et al., 1988, p. 167)

As an applied research and development center, CTD will coordinate activities of Bangalore's major high-tech players (R&D institutes, state government, private industry, and venture-capital firms), helping with (1) technology selection, (2) technology development, (3) technology transfer, and (4) technology commercialization initiatives. CTD's main focus will be to enhance buyer-seller relationships.

Lessons Learned

What lessons can be learned about technology transfer from such cases in Bangalore as ISRO, IISc, C-DOT, ancilliary industries, TDICI, UNIX, Texas Instruments, RRI-BEL, and U.S. AID's Center for Technology Development?

(1) R&D institutes can make heavy profits (through license fees, etc.) by transferring technological innovations to private industry. ISRO in Bangalore earns about half of its annual R&D budget by transferring technologies to private industries.

(2) R&D institutes that conduct high-tech defense research (and have classified security status) can facilitate the transfer of their nonmilitary technological innovations to private industry by establishing autonomous technology transfer entities; for example, ISRO's establishment of an autonomous technology transfer corporation.

(3) Technology transfer can be facilitated through sharing of R&D facilities, people exchange, and faculty consultation, as illustrated by the activities of IISc's Center for Scientific and Industrial Consultancy.

(4) R&D institutes need to find a balance between basic and applied research. For example, C-DOT conducts basic and applied research in the area of telecommunication technology, representing an organizational model for Indian R&D institutes.

(5) Some of the best technology transfer occurs when individuals move from one location to another. For example, Sam Pitroda's return to India brought home not just the individual, but also state-of-the-art telecommunications technology that Pitroda helped develop in the United States.

(6) Ancilliary industries represent a potential vehicle to transfer technology from large high-tech companies to the commercial marketplace. Not much of this potential has been realized to date, as Bangalore's ancilliaries are generally captive suppliers to large high-tech companies.

(7) Ways to enhance the purity of Bangalore's high-tech environment must be found to trigger a self-sustaining chain reaction in Bangalore's critical mass of companies. The availability of venture capital (provided by TDICI and state financial institutions), and of technomanagerial support to entrepreneurs are crucially important in fueling high-tech growth in a technopolis.

(8) Technology transfer need not always be from Western industrialized countries to Third World countries. The Indian expertise in UNIX represents a spectacular case of reverse technology transfer, from a Third World country to Western industrialized countries.

(9) Technology transfer can go beyond the mere transfer of a hardware technology or individuals, and include transfer of organizational structures, work environments, and managerial innovations. For example, Indian engineers at TI's Bangalore facility work in an American-style management system, much like their counterparts in Dallas.

(10) Advances in communication technology—for example, the availability of a dedicated satellite link for data transfer (as in the case of TI)—minimize the barrier of geographical distance in the international transfer of brainpower. Communicating via a satellite link, however, does not substitute entirely for face-to-face interaction, especially when developing complex computer software codes.

(11) Employee turnover and attrition is one effective way of technology transfer in high-tech firms. Engineers who leave high-tech companies to join others or to spin off their own companies carry with them the technical know-how learned in their parent companies.

(12) An apathetic, inefficient bureaucracy can be anathema for technology transfer efforts, especially when the lead time to exploit a technological innovation commercially is small. For example, the RRI-BEL project on LCDs got nowhere because of apathy from India's central government in New Delhi.

(13) Indigenous technology development and technology transfer arrangements compete with options of imported foreign technology. National governments and private industries need to weigh carefully the pros and cons of developing indigenous technologies versus the option of importing ready-made foreign technologies.

(14) Synergy between participating organizations (R&D institutes, government agencies, private industries, venture-capital firms, and entrepreneurs) is important in the transfer of technology. An umbrella organization, like the U.S. AID-sponsored Center for Technology Development in Bangalore, can serve as a coordinator and catalyst in the technology transfer process.

Notes

1. A high-tech industry is also characterized by (1) a high proportion of highly-skilled employees, many of whom are scientists and engineers, (2) a fast rate of growth, (3) a high ratio of R&D expenditures to sales (typically about 1:10), and (3) a worldwide, highly competitive market for its products (Rogers & Larsen, 1984).

2. High-technology growth also can be found in other urban centers such as Pune, Chandigarh, Delhi, and Bombay.

3. Indian industries are classified as large, medium, and small based on the amount of start-up capital investment: large-scale industries represent an initial investment of more than $2.2 million (U.S.); medium-scale industries represent an initial investment of between $220,001 to $2.2 million; and small-scale industries represent an initial investment between $16,250 to $220,000.

4. Sales figures are computed at an exchange rate of 16 rupees to one U.S. dollar.

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