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INDIA'S HIGH-TECH MICROELECTRONICS REVOLUTION*

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Abstract—The microelectronics industry is one of the driving forces of an information society. Since 1984, the Indian government has promoted such high-technology industries as semiconductors, telecommunications, and computers. High-technology industries in India are getting off to a promising start. But a higher degree of collaboration between research and development (R&D) institutes, private industry, and the national government are needed if the full potential of high technology in India is to be realized.

INTRODUCTION

The United States, Japan, and most Western European nations in recent decades have become *information societies*, countries in which information workers are more numerous than such occupational categories as farmers, industrial workers, or service workers (Rogers, 1986). In an information society, information is the crucial ingredient, much like energy was in the industrial society of an earlier era. The computer is the most important tool in the information society, just as the steam engine was the basic technology in the industrial society. The transition of the United States to an information society has been the focus of considerable scholarly research (Machlup, 1962; Bell, 1973; Porat, 1978; Beniger, 1986).

A high-technology microelectronics industry is one of the driving forces of an information society. A *high-technology industry* is one in which the basic technology underlying the industry changes very rapidly. 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 research and development (R&D) expenditures to sales (typically about 1 : 10);
4. A worldwide, highly competitive market for its products (Rogers & Larsen, 1984).

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Microelectronics, the part of the electronics industry centering on semiconductor chips and their applications (such as in computers and telecommunications), is usually considered the highest of high technology. Some enthusiastic observers claim that microelectronics potentially represents a new type of "industry" that can allow a Third World nation to leapfrog the industrial era so as to become an information society (Singhal & Rogers, 1989a).

Several Third World countries such as Singapore, South Korea, Taiwan, Brazil, Mexico, Egypt, and India are attempting to create an indigenous high-technology microelectronics industry. Former Indian Prime Minister Rajiv Gandhi (who served from 1984 to 1989) issued government directives for the early beginnings of what may become a microelectronics revolution. Since late 1984, when Rajiv Gandhi became Prime Minister, the Indian government has promoted indigenous businesses in semiconductors, telecommunications, computers, and computer software (Sambharya, 1986; Singhal & Rogers, 1989b). From 1984 to 1989 in India, the number of computers increased fifteen-fold, computer software exports increased eight-fold, and the computer industry's revenues increased five-fold (Singhal & Rogers, 1989b). So high-technology microelectronics development is starting to get underway in India on a serious basis.

This article analyzes the recent growth of microelectronics industry (including its applications in telecommunications, computers, and computer software) in India.

HIGH-TECH GROWTH IN INDIA

India is primarily an agricultural nation. In 1990, nearly 70% of India's workforce are engaged in farming, although agriculture accounts for only 33% of India's gross national product (GNP). Some 20% of the Indian work force is employed in industry, which accounts for 25% of India's GNP. The remaining 10% of the Indian work force are white-collar workers employed in service and information jobs; they account for a huge 42% of India's GNP (Singhal & Rogers, 1989b). India is far from becoming the type of information society that is represented by the United States or Japan, where a majority of the laborforce is composed of information workers. But if one counts money instead of workers as the best index of progress toward becoming an information society, India is well on the way.

India is unique among Third World nations in that it has much of the infrastructure needed for high-technology development. India ranks third, after the United States and the United Socialist Soviet Republic, in scientific and technical manpower. The Indian population contains 3 million scientists and engineers, and the Indian government invests over $2 billion (U.S.) annually in R&D. About 1,300 Indian R&D institutes, mostly government-funded, conduct specialized research in atomic energy, space, defense, electronics, aeronautics, agriculture, and health. Some 225 institutes exclusively pursue R&D in electronics. Research and development by private companies, while limited, is growing. Thirteen percent of India's R&D expenditures comes from the private sector, as compared to 55% in the United States. India spends about 1% of its gross national product on R&D, as compared to about 2.5% in the United States (National Science Foundation, 1987).

Engineering education is currently offered by 80 Indian universities to 750,000 students (Rahman, 1986). The five Indian Institutes of Technology provide a high-quality university-level education in computer science, electronics, electrical engineering, and other engineering disciplines. But Indian science regularly loses its best-trained people, as thousands of Indian engineers migrate to the United States for graduate-level study, and then stay in the United States for employment with high-tech firms. Of the approximately 22,000 Indian students studying in U.S. academic institutions, about 60% are pursuing degree's in science and engineering programs. Indian students are 2.5 times more likely to remain in the United States than are students of other countries. Indians have the highest per capita income of any ethnic group in the United States, and this high socioeconomic status, compared to the much lower salaries these individuals would earn in India, is a basic reason for the India-to-America brain-drain (Singhal & Rogers, 1989b).

While the Indian government currently promotes entrepreneurial activity, serious limitations to the founding of high-tech firms still exist. Banks provide start-up loans and subsidies to qualified entrepreneurs, but government licensing and clearance procedures are often complex, slow, and frustrating. While the Indian government invests heavily in technical education and in research institutes, few technological innovations are actually transferred from public R&D organizations to private companies. Until 1986, venture capital for high-tech start-ups was virtually nonexistent in India. In 1989, a few venture capital firms in India offered limited start-up funds. But many entrepreneurs must borrow their start-up capital from family members or from other sources. The Indian mass media give little attention to successful entrepreneurial role models, and hence, entrepreneurial spirit spreads slowly.

Bangalore: India's Silicon Valley

High-tech companies in India are particularly agglomerated in the cities of Bangalore and Pune, although high-technology growth can also be found in other urban centers like Chandigarh, Hyderabad, Delhi, and Bombay. *Agglomeration* is the degree to which some quality is concentrated spatially in one area (Rogers & Chen, 1990). Why Bangalore and Pune? Each have the specialized infrastructure for high-tech industry: Buyers and suppliers, financial institutions, markets, political support, an attractive climate, a high quality-of-life, and a strategic military defense position (Singhal, Rogers, Sawhney, & Gibson, in press).

Bangalore is located 3,000 feet above sea level in the Karnataka state of South India, and has very pleasant weather throughout the year, reminiscent of California's Silicon Valley. Silicon Valley is the world's largest and most widely-known technopolis. A *technopolis* is a geographically concentrated high-tech complex which is characterized by collaborative relationships between government, private firms, and research universities, and by the presence of venture capital and entrepreneurial spin-off firms (Rogers & Chen, 1990). Bangalore is "India's Silicon Valley," home to the largest public sector high-tech firms, many of which are involved in defense-related work: Bharat Electronics Limited (a defense contractor), Hindustan Aeronautics Limited (producer of supersonic MIG aircraft), the Indian Department of Space (which designs, develops, and launches communication satellites), Indian Telephone Industries (manufacturer of telecommunications equipment and electronic exchanges), Hindustan Machine Tools (producer of state-of-the-art machine tools and precision watches), Bharat Heavy Electricals Limited, and Bharat Earth Movers Limited (Singhal, 1989). These public sector firms have encouraged the establishment of ancillary and subcontracting companies, most of which are agglomerated in Bangalore. In addition, the National Aeronautics Laboratory, the Aeronautical Defence Establishment, the Electronics and Radar Development Establishment, the Gas Turbine Research Establishment, and the Central Power Research Institute are headquartered in Bangalore.

Bangalore's premier research university is the Indian Institute of Science (IISc), which in the 1930s was headed by India's only Nobel Prize winning physicist, C. V.

Raman. The Indian Institute of Science provides high-quality education and research in such high-technology areas as electrical engineering, computer science, material science, aeronautical engineering, and biotechnology. Through IISc's Center for Scientific and Industrial Consultancy (established in 1973), technological innovations developed in IISc's R&D labs are transferred to private industry in Bangalore. Efforts are underway to boost commercialization of technological innovations through a strengthened academic-industry collaboration. In addition to IISc, Bangalore has several engineering colleges and polytechnics (more than any other Indian city) which produce scientific and technical personnel for its high-tech industries (Singhal, 1989; Varma, 1989).

Bangalore is also India's fastest growing city with a current population of about 4 million people; 30 years ago Bangalore's population was only 1 million. Large and small industries are increasingly establishing their operations in Bangalore, attracted by the pleasant climate and the availability of technical manpower. In the past decade, more than 350 medium-sized industries were established in Bangalore, and the number of small-scale industries increased from 800 to 10,500. Bangalore has eight large industrial parks, including the Peenya Industrial Estate, the largest in India (Singhal, Rogers, Sawhney, & Gibson, in press).

The Karnataka State Electronics Development Corporation (KEONICS) has established a 350-acre Electronics City, located 12 miles from the Bangalore city center. Special financial incentives and tax concessions are provided to electronics companies that locate their operations in the Electronics City. Sales by companies located in Electronics City are estimated to rise from $200 million (U.S.) in 1989 to $800 million (U.S.) by 1991, creating 12,000 new jobs in the process (Varma, 1989).

Bangalore is also the headquarters of Technology Development and Information Company of India (TDICI), a private venture capital company established in 1988. By mid 1989, hardly a year in existence, TDICI invested $120 million (U.S.) in 36-high-technology ventures, several of which are located in Bangalore (Singhal, 1989).

Technology park in Pune

The city of Pune in Maharashtra state is also a promising high-tech microelectronics center. Pune has about 5,500 small-scale firms, and about 150 large- and medium-sized companies. Some 550 of these firms are in electronics manufacturing or assembly, a number steadily growing during the 1980s (Singhal & Rogers, 1989b).

The University of Pune has established a technology park near its campus to foster industry-academic collaboration. The University has advanced computer facilities, and excellent academic programs in the physical sciences, but lacks an engineering school. The University of Pune is leasing 200 acres of its land to local engineering firms in order to provide testing facilities for these private firms, to exchange technological innovations with them, to train personnel for industry, to promote entrepreneurship among university students, and to encourage faculty consulting with the local high-tech firms.

One high-tech entrepreneur, J. R. Karandikar, has recently benefitted from the University of Pune's commitment to academic-industry collaboration. In 1987, Karandikar imported a state-of-the-art laser-cutting machine from the United States, and created a new company around this technology, which he located in Pune. Karandikar's company is the first in India to provide laser-cutting services. A laser-cutter replaces the conventional dies and tools used in metal-cutting, drilling, and other machine tool operations. The University of Pune provided Karandikar with technical know-how, in return for certain hours of free use of the laser-cutter for research purposes. Karandikar made eight trips to Delhi in order to obtain the 35 necessary government clearances and licenses, and over 100 trips to Bombay for similar purposes. Six million dollars (U.S.) were invested in the new firm, of which 80% was provided by the Indian government (Singhal & Rogers, 1989b).

SEMICONDUCTORS

How did the semiconductor industry get started in India? In the early 1960s, a few Indian companies produced germanium semiconductors. In 1964, Continental Device India Limited brought silicon semiconductor technology to India, in a collaborative agreement with Continental Devices of the United States. In the mid 1960s, Fairchild Semiconductors of the United States was shopping in Asia for a location for its offshore semiconductor manufacturing plants. Fairchild seriously considered India as a possible location, but the Indian bureaucracy scared them off, and they established their semiconductor plants in Penang (Malaysia) and in Manila. In the late 1960s, Bharat Electronics Limited (BEL), a large government defense equipment manufacturer headquartered in Bangalore, collaborated with RCA to acquire germanium and silicon technology for producing semiconductor chips.

The rapid advances in microprocessor chip technology in the United States in the 1970s, and their subsequent adoption in India, created a potential for high-tech microelectronics, reliable telecommunications, low-priced computers, and computer software in India. The microelectronics industry in India grew slowly during the 1970s, but began to take-off in the 1980s, spurred by the favorable high-tech policies of the Rajiv Gandhi government.

In 1984, Semiconductor Complex Limited (SCL) was established by the Indian government in Chandigarh at a cost of $40 million. Semiconductor Complex Limited formed technology licensing agreements with Hitachi, AMI, and Rockwell, and began producing semiconductor chips, which were about one generation (three to four years) behind the state-of-the-art in the United States. In 1989, an accidental fire completely burned down SCL's chip design and manufacturing facility, delivering a severe blow to India's indigenous capability in microelectronics. The SCL facility is now being rebuilt at a considerable public investment (about $50 million).

The Indian semiconductor industry has carved out a unique worldwide niche. While cutting-edge semiconductor chips are imported from U.S. companies like Intel, Motorola, and Rockwell for use in Indian computers, less technologically advanced chips are produced in India. India exports older-generation semiconductor chips, which have been phased out by semiconductor producers in most other countries. So the Indian semiconductor industry has found its niche well behind the cutting edge of technology. But the present scenario may change as U.S. semiconductor giants, Intel and Motorola, are now beginning to consolidate their presence in India. Both Intel and Motorola have identified India as a "strategic" country (from a business perspective), opening company offices in Bangalore and New Delhi, respectively. India is positioned ideally to capitalize on the growing worldwide market for Application Specific Integrated Circuits (ASICs). Two Indian companies, Indian Telephone Industries, and PSI Data Systems, both located in Bangalore, conduct state-of-the-art R&D in ASICs.

TELECOMMUNICATIONS

Telephones arrived in India in 1881, when a 50-line manual telephone exchange was installed in Calcutta, the then capital of British-ruled India (Ghorpade, 1986). Some 109 years later, in 1990, India reputedly has the world's worst telephone service, with only 0.4 telephones per 100 residents, compared to 75 in the United States, 65 in Japan, and 7 in Malaysia (Chowdary, 1988). Only 8,000 of India's 600,000 villages have a rural telephone exchange. Of India's 40,000 telephone exchanges, most are obsolete Strowger and Crossbar exchanges (which use a combination of electromechanical moving parts for switching telephone calls in the exchange). These exchanges experience more wear and tear than digital electronic exchanges, and they are affected by temperature, moisture, and climactic conditions.

The Rajiv Gandhi government, realizing the importance of advanced, widely-accessible telecommunications, announced a new telecommunications policy in 1985. This policy:

1. Permitted foreign collaboration with the Indian private sector in manufacturing indigenous telecommunications equipment;
2. Created a Department of Telecommunications by bifurcating the Indian Posts and Telegraph Department; and
3. Created autonomous telephone corporations to serve Delhi and Bombay (Chowdary, 1986).

In 1984, Satyan "Sam" Pitroda, an overseas-returned Indian (formerly an executive of Rockwell, Inc. in Chicago), founded the Center for Development of Telematics (C-DOT) in New Delhi. Pitroda's R&D organization has developed state-of-the-art telephone switching equipment to serve India's special telecommunications needs. Indian telecommunications are characterized by 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 is headquartered in a former luxury hotel in New Delhi. Pitroda created an egalitarian organizational culture, as free as possible from bureaucratic strictures, emphasizing target achievement through human resource management and strong leadership. He hired 400 young engineers and provided them with an opportunity to carry out state-of-the-art R&D in a pleasant work environment. The average age of C-DOT employees when it began in 1984 was 23. A typical employee works 10 to 12 hours per day.

C-DOT accomplished most of its R&D goals, saving $3.5 million of its $29 million budget allocations in the three-year period between 1984 and 1987. C-DOT successfully developed the technology for electronic PABX systems, developed a 128-line rural telephone exchange, and then tested 4,000-line and 16,000-line telephone exchanges. Several government and private companies were then licensed to manufacture C-DOT's electronic telephone exchanges. A second three year C-DOT mission was announced in 1987 to develop technological prerequisites for a future Integrated Systems Digital Network (ISDN) in India.

Telephones: From luxury to necessity

Almost all of India's telephones are located in urban areas, where only about 25 percent of India's 800 million people live. The average annual telephone bill in India is much higher than the $240 (U.S.) annual per capita income of the Indian population. Obviously the urban-rich are the primary users of telephones in India. Although a telephone is considered a luxury by the average Indian, business and industry realize the compelling necessity of reliable telecommunication services.

Kittur is a village in Karnataka state in South India with a population of 12,500. This village served as a pilot project in which a 128-line rural automatic exchange (RAX), developed by C-DOT, was installed in mid 1986. The 74 subscribers consisted of local farmers and small businessmen. They averaged an amazing 2,400 calls per telephone per year. An evaluation of the impacts of the 74 telephones in Kittur found an 80% increase in cash deposits at local banks, an increase of 20–30% in local business incomes, and easier, more rapid access to medical doctors for local residents in health emergencies. Neighboring villages now demand a similar telephone service.

The Kittur experience with the automatic rural telephone exchange has been hailed as a success. The Kittur Project is helping change the image of the telephone in India from being perceived as a luxury, to its perception as a business necessity.

The boom in telecommunications

In previous decades, the growth of the Indian telecommunications sector was stymied because of underinvestment. In 1989, India's annual telecommunications budget of about $1 billion (U.S.) made it one of the top-20 spender nations in telecommunications. Between 1989 and 2000, India will spend an estimated $40 billion for its telecommunications development, increasing the number of telephone subscribers from about 5 million in 1990, to an estimated 25 million by the year 2000. The Indian government installed one RAX every day between 1988 to 1990. Each RAX provides 50 telephone lines, serving about 4,000 telephone subscribers. Long distance direct-dial subscriber-trunk-dial (STD) facilities are available at 350 locations in India, up from 250 locations in 1985. Indigenously-assembled electronic push-button telephones, cordless telephone equipment, and answering machines are now available in the Indian market. Seven Indian companies, in collaboration with Ericsson of Sweden and Siemens of West Germany, produce high-quality electronic push-button telephones, which have an average life of 20 years (compared to the 5-year average life of India's electro-mechanical, rotary telephone instruments). So India's telecommunications revolution is well underway.

COMPUTERS

Until recently, growth of the computer industry in India was slow. India's first computer was installed at the Indian Statistical Institute in Calcutta in 1955. By 1972, there were 170 computer systems nationwide, 75% of which were International Business Machines (IBM). In 1972, an effort was made to start an indigenous computer industry by providing the Electronics Corporation of India Limited (ECIL), a government subsidiary, with carte blanche to manufacture computers in India. Between 1973 and 1978, ECIL installed 94 computer systems in India.

In the late 1970s, a minicomputer policy was evolved by the Department of Electronics, the primary government agency controlling the growth of the electronics industry in India. IBM was asked to leave India in 1977, when it refused to allow majority (greater than 50%) Indian ownership of the company in India. A central government corporation, Computer Maintenance Corporation, was then established to ensure the availability of spare parts and the maintenance of computers in India. The introduction of microcomputers in the United States in the late 1970s, and their subsequent adoption in India, created a large potential computer market in India (Singhal & Rogers, 1989b).

The real spark for the computer industry in India came from Rajiv Gandhi, who became Prime Minister in November, 1984, after his mother's assassination. When Prime Minister between 1984 to 1989 Rajiv Gandhi was India's and perhaps the world's, first high-tech head-of-state: A ham radio operator, an audiophile, an avid computer user, and a strong believer in the potential of technology. Gandhi announced a new computer policy which liberalized imports and encouraged the adoption of prevailing international standards. As Prime Minister, Rajiv was technically appropriate for leading India toward growth in high-tech microelectronics. His successor, V. P. Singh, a former Finance Minister in Rajiv Gandhi's Cabinet, seems equally supportive of India's emerging microelectronics-based revolution. Government policy, and the individual who makes the policy, are important factors in launching high-tech industries in a Third World nation, and in diffusing to the public the communication technologies that high-tech microelectronics produces (Singhal & Rogers, 1989b).

The booming computer industry

Spurred by the government's liberalized computer policies, the computer market in India has grown sharply in recent years, as have the sales of the Indian computer industry (Figure 1). India's computer industry sales increased from $96 million (U.S.) in 1983–84, to $270 million in 1986–87, to $488 million in 1988–89.

Valuable lessons for high-tech computer growth in India can be learned from the experiences of two leading computer companies: (1) Hindustan Computers Limited (HCL), and (2) WIPRO Information Technology Limited (WITL). HCL was started when six young engineers, lead by Shiv Nader, quit Delhi Cloth Mills (DCM) Data Products in 1975 to start a spin-off which lead a price war for pocket calculators. HCL grew from 8 employees in 1976 to 3,000 in 1990, of which 70% are engineers and MBAs. In 1989, HCL was India's largest computer company with sales of $90 million, up 100% from the previous year (*Dataquest*, 1989). HCL has spun-off ten other in-house high-tech companies, one during each year of its life. One such HCL company, HCL America, established its headquarters in Silicon Valley (in 1989) to tap the U.S. computer market. So HCL is a very fertile entrepreneurial breeding ground (Singhal & Rogers, 1989b).

WIPRO started as a cooking oil and consumer products company several decades

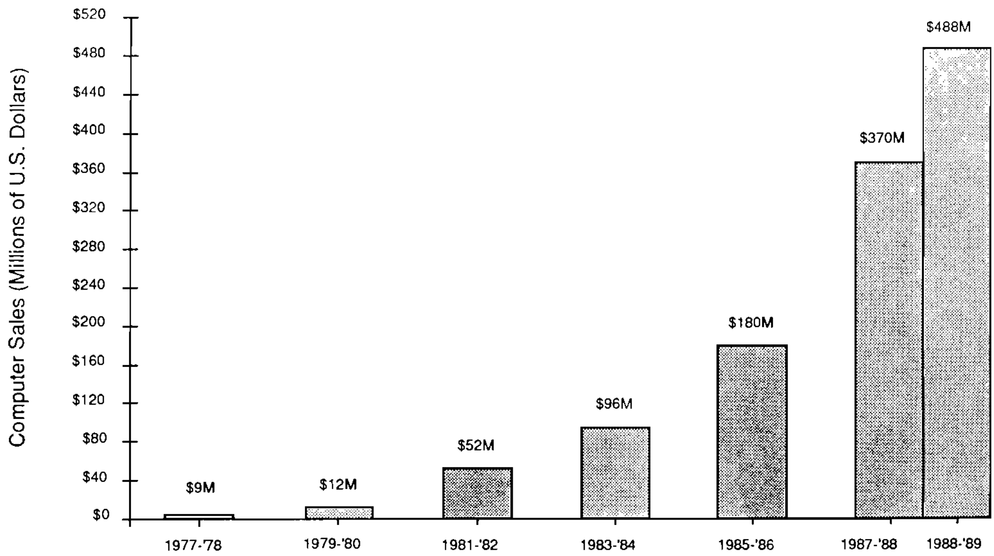

Figure 1. Sales of Indian computers. Source: *Dataquest* (1989).

ago. In 1982, WITL was spun off, with the parent company playing the role of "venture capitalist." WIPRO's computer sales went up from $7 million (U.S.) in 1984, to $23 million in 1986, to $70 million in 1989. WITL is headquartered in Bangalore, and has spun-off Wipro Systems, a computer software company (Singhal & Rogers, 1989b).

Microcomputers are the fastest-growing segment of the Indian computer industry, and are projected to exceed the share of the market earned by minicomputers in a few years. As a result of HCL's price war strategies, microcomputer prices declined from about $4,000 in 1986 to about $1,500 in 1988 (Chellam, 1987). In 1990, the Electronics Trade and Technology Development Corporation (ET&T), a government undertaking, introduced a low-cost microcomputer (IBM PC clone) in India for $800, fuelling another price war in the microcomputer market. Small microcomputer companies, unable to withstand the tough price competition, are losing out. A similar "shakeout" of the U.S. microcomputer industry occurred in the mid 1980s when the total number of microcomputer firms dropped from 250 to about half that number.

Railways, airlines, and banks are increasingly computerizing to streamline operations. The computerized reservation system, installed in the New Delhi Railway Station, has cut down passengers' waiting time in the reservation queue from an average of 80 minutes to five minutes (Khan, 1987). Several sophisticated nationwide computer networks are in service. One is NICNET, created by the National Informatics Center (NIC), to exchange information between government ministries and departments. NICNET will be extended to provide district-level coverage in each of India's 439 districts (the basic unit of government in India).

An illustration of how a microcomputer can revolutionize local administration occurred in Karwar District in Karnataka State, the site of a novel experiment in computer technology. Since 1984, a microcomputer has been successfully utilized in the local district headquarters as an analytical tool. The district administrator diverted funds that had been allocated for a jeep in order to purchase a microcomputer. The first year after adopting the computer, Karwar District moved up from 18th to 3rd rank (in Karnataka state), in terms of successfully implementing development programs. Much of this improved performance was credited to the district administrator's microcomputer, which he used to monitor the progress of development projects in his district. As a result of the Karwar District experience, a Computerized Rural Information Systems Project (CRISP) has been expanded to several more Indian districts to provide local officials with a monitoring system (Singhal & Rogers, 1989b).

COMPUTER SOFTWARE

The Department of Electronics estimates that Indian computer software exports will increase seven-fold from $35 million in 1986 to $240 million by 1990. In 1989, India's share of the world $60 billion (U.S.) software market was only about 0.2 of one percent ($100 million). The computer science and engineering departments of the IITs and regional engineering colleges (REC's) graduate several thousand engineers each year, whose salaries are about one-tenth that of comparable salaries in industrialized countries like the U.S. Software design and development is labor-intensive, which fits India's resource situation.

In 1987, the United States-headquartered Texas Instruments established a software development center in Bangalore. G. R. Mohan Rao, an Indian-born vice president of TI, accompanied the company president to India in 1983. They were favorably impressed by the high caliber of Indian engineers, the attractive climate in Bangalore, the relatively cheap brainpower of India, and the favorable political climate in New Delhi towards high-tech. TI decided to establish a software design facility in Bangalore, and government approval was secured in 1985. TI's software facility in Bangalore represents an investment of $5 million (U.S.) and is 100% United States-owned, so it represents an exception to the general government policy of requiring majority ownership of Indian computer companies (Rozeboom, 1988). TI-Bangalore carries out computer-aided-design of very large scale integration (VLSI) circuits. Its work is linked to TI-Dallas by satellite, which transmits the software code. TI employs some 120 Indian engineers and physics graduates, mainly from the Indian Institute of Technology's (IIT's). They are paid a beginning salary of about $200 (U.S.) a month, reasonable by Indian industry standards, but only about one-tenth of what TI would pay equivalent employees in the United States. The Indian engineers at TI say they are happy learning state-of-the-art VLSI design in a pleasant work environment.

Building on the prior experience of TI, other U.S. high-tech conglomerates like Hewlett–Packard and Digital Equipment Corporation have established similar 100% software export operations in India. The Texas Instruments operation in Bangalore illustrates the potential of software development in India, where English language ability, technical trained personnel, and relatively lower salaries provide a strong competitive advantage in the worldwide market.

DISCUSSION

India has many ingredients for developing high-tech industry: Political will, relatively low-cost brain power, low labor costs, good quality universities, R&D investment, a large domestic market, and tremendous capital and microelectronics expertise among United States-based expatriate Indians. Most high-tech R&D in India is funded and/or conducted by the government, rather than by research universities. Most Indian R&D institutes place a low value on the use of their research results, and so technological innovations are seldom transferred to industry (the Indian Institute of Science in Bangalore, C-DOT, and a few other R&D institutes are exceptions, not the rule). A strengthened technology-transfer arrangement between R&D institutes and private industry could give a significant boost to India's high-tech microelectronics development.

Disparities exist in the funding of Indian universities; the IITs are well-endowed, but other universities lack facilities and resources. India needs more research universities that are strong in microelectronics.

Brainpower is available in India, and is relatively cheap (compared to Euro-America and Japan). The brain-drain to the United States, especially of India's IIT graduates, is problematic. However, this brain-drain could easily be turned into "brain-gain." Several returned Indians from overseas have given a tremendous boost to high-technology in India: For example, Sam Pitroda came home to direct the Center for Development of Telematics. A strengthened reverse brain-drain could give a tremendous boost to India's microelectronics industry. Appropriately, in California's Silicon Valley, where 6,000 Indian engineers carry out state-of-the-art high-tech work for U.S. companies, an association of Indian professionals, Silicon Valley Indian Professional Association (SIPA), helps forge high-technology bridges between the United States and India. Formed in 1987, SIPA has begun to play a key role in fuelling India's high-tech microelectronics development through United States-based Indian expatriates (Sawhney & Singhal, 1990).

Collaboration among electronics firms is important in the development of high-technology industry (Ouchi, 1984). Even companies that are competing with others in the same industry (such as computers or semiconductors) for lower prices and higher quality products may collaborate with each other through an R&D consortia. Several such collaborative centers in microelectronics were launched in Japan (the VLSI Project) and in the United States (the Microelectronics and Computer Technology Corporation) in the 1980s. Such a collaborative relationship seems to fit naturally with Japanese culture, and is gradually being learned in the highly competitive U.S. microelectronics industry. But in India, such collaboration is not very highly valued at present.

Several other problems restrict the future development of the high-tech microelectronics (and telecommunications and computer) industry in India:

1. Barriers to indegenization, for example, the prevalence of "screw driver" mentality in the Indian computer industry leads to importing completely knocked-down (CKD) computer kits from overseas, which are then assembled and sold domestically;
2. Infrastructural deficiencies, for example, unreliable telephone service and frequent power spikes;
3. Shortage of computer-trained manpower (despite an abundance of scientific and technical personnel);
4. Widespread software piracy;
5. The absence of a computer culture (Singhal & Rogers, 1989b).

If high-technology microelectronics continues to grow in India, it will create jobs and wealth, although these impacts will at best be relatively minor in a huge nation like India. More important are the social impacts of the high-tech microelectronics products (improved telephones, lower-priced computers, etc.), which can aid the further development of business in India, change the lifestyles of the population, and eventually move the nation toward becoming an information society. However, on the basis of other nations' experiences with high-tech microelectronics, India should expect that these benefits will come at a certain human cost. A major problem that comes with high-technology industry is wider socioeconomic inequality, as California's Silicon Valley illustrates. Further, the workstyles and lifestyles of high-tech U.S. employees do not fit well with Indian values. For example, cutthroat competitiveness, a stress on material gain, and high divorce rates which characterize U.S. technopolii like Silicon Valley, clash with fundamental Indian cultural values.

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