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Issues in the Technological Development of China's Electronic Sector

Anupam Khanna

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A Background Study
for
China: Long-Term Development Issues and Options

CHINA

Long-Term Development Issues and Options

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Abstract

This paper examines China's electronics industry and its scope for development by considering its application to other indigenous industry, at what level and by what means development should occur, and what institutional structures will need to be set up.

Table of Contents

1. INTRODUCTION

1.01 The electronics sector occupies a strategic position in the economy of countries such as China and there are two aspects to its importance, especially as it relates to the modernization of Chinese industry. First, since electronic products can fulfill a variety of human needs, there is a burgeoning demand for them within Chinese and international markets. In addition to devices performing new functions, there is also the demand derived through the substitution of nonelectronic products and parts with electronic ones. Consequently, the electronics sector is growing rapidly in absolute terms and is destined to account for an increasing share of industrial output. Second, the modernization of technology across all segments of the industrial sector is synonymous with the application of electronic systems to industrial processes and capital equipment.

1.02 It is beyond the scope of this paper to analyze comprehensively the current status and technological level of the electronics industry in China or to forecast the exact nature and extent of its role in the Chinese economy of the future. From the experience of other countries, it is clear, however, that future development in the production and use of electronic goods in China will involve the following phenomena:

(a) introduction of new or better productive processes which improve the efficiency of operations in the electronics and associated industries;

(b) introduction of new electronic products and improvement of existing ones which are currently manufactured or can be produced by the industry;

(c) development of the capability of the industrial sector to use new electronic products and processes as contrasted with the ability to produce them; and

(d) development of the industrial sector's capability to undertake and sustain the above phenomena, especially in view of the rapid advance of electronics technology.

1.03 What are the constraints and prospects for these processes in China? This is the central concern of this paper with particular emphasis on the economic aspects of the acquisition, assimilation, adaptation, innovation and diffusion of electronics technology by Chinese industrial enterprises. The analysis and suggestions are based primarily on a few lessons derived from the experience of other countries which may be relevant for China.

Background

1.04 The Chinese electronics industry comprises around 3,000 enterprises employing approximately 1.4 million people. The gross value of output (in 1980 prices) was Y 14.0 billion in 1983, representing 2.3 percent of the output of industry as a whole. The product range is fairly diversified and includes goods in each of the major categories of electronics products, namely consumer electronics (for example, TVs, radios, tape recorders), professional and industrial equipment and instrumentation, computers, radar and communication equipment, as well as electronic components including semiconductor devices. In terms of technological sophistication, about 600 of the 3,000 enterprises have fairly advanced production capabilities and, of the total employment, advanced scientific and technical personnel number around 50,000.

1.05 Although the electronics industry in China has come a long way since 1949, Chinese authorities readily acknowledge that it is at least 15-20 years behind the technological level of the United States and Japan. Until recently, except for the initial post-liberation period when the Soviet Union provided technical assistance, the Chinese electronics industry developed almost exclusively on know-how acquired through published literature, reverse engineering, and by a process of trial and error. While there is no doubt that a substantial technological and scientific base has been established, particularly through learning-by-doing, the general lack of adequate contact with the industrialized world, coupled with the upheavals of the cultural revolution, have resulted in significant weaknesses in the civilian electronics subsector. These are most apparent in the cost and performance of Chinese electronics products, even relatively mature ones. For example, in spite of low wages for labor, a 14-inch black and white TV receiver is priced at Y 400 ($200) or above in the retail market and the mean time between failures (MTBF) is typically between 3,000 and 5,000 hours. In more advanced products, a World Bank industrial sector mission in 1983 estimated that the costs of small- and medium-scale integrated circuits (SSI/MSI) were four to five times higher than in the United States or Japan, and for electronic systems, were five to ten times higher. For large-scale integrated (LSI) circuits, such as 1K random access memory (RAM) chips which are well below the state of the art in industrialized countries today, the cost was almost eighty times as much, which casts severe doubt on the commercial viability of the production technology. Chinese users of industrial electronics (for instance, machine-tool manufacturers) often find the reliability of domestically produced systems and components to be poor and complain about lack of software and after-sale service.

1.06 The problems alluded to above can, in general, be traced to a combination of technological and economic factors.1/ While many of the problems can be identified and corrected with the appropriate transfer of know-how and better technology from within and outside China, it should be emphasized that the process of transfer is not without costs and, secondly, a one-shot attempt at infusing advanced technology or modern equipment will not be sufficient to ensure sustained future competitiveness and productivity improvements. The correct approach is to develop a strategy for upgrading technology in the electronics sector and to help implement it by ensuring an appropriate institutional structure and policy environment.

1.07 There should hardly be any need to belabor the economic importance of industrial technology development for electronics in China since it is clear to most observers that the economic return to Chinese society of such efforts can be very high. Not only can improvements in process or manufacturing technology significantly increase productivity in the electronics sector, but also electronics-based innovations in capital machinery and equipment used by other industrial sectors can lead to major increases in their productivity, as they have done in other parts of the world. An important consequence of electronics technology development in China, which is not readily apparent from productivity statistics, will be an improvement in product quality. Besides the direct economic benefits of superior quality and better performance of electronics products provided to the Chinese population, it will also be instrumental in enlarging China's exports in international

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1/ Five factors may be identified: (i) high cost and low quality of inputs; (ii) high rate of defects due to manufacturing problems; (iii) small scale of production; (iv) inappropriate factor mix; and (v) cost-plus pricing.

markets. It should be recognized that nonprice factors such as reliability, serviceability, efficiency, durability, weight, functional versatility and design are extremely critical in most markets for modern manufactured products, where they often overshadow price considerations. This is true not only for industrial products such as computers and control systems, but also for consumer durables such as television receivers.

2. APPLICATIONS OF ELECTRONICS IN INDUSTRY

2.01 Many observers attribute the current phase of the microelectronic revolution to the advent of the microprocessor--a computer on a chip--which made its first appearance in 1971. This device and associated components, such as memory chips, have made it possible to incorporate, cost-effectively, fairly sophisticated information-processing capabilities in a variety of consumer and producer goods, and have also given birth to totally new products such as personal computers, monitoring devices and automation technology.

2.02 The primary use of information-processing capabilities in existing industrial operations is for monitoring and control, functions performed earlier by manual or electromechanical means or that were simply impossible to do. In China, the Shanghai No. 6 Textile Factory has pioneered the use of a computer system for monitoring its 464 looms weaving grey fabric. It is a simple, domestically produced system, even primitive by Western standards insofar as the computer itself is concerned, but it has had a significant impact in increasing the productivity of the factory by providing timely information on the operating status of the looms to staff on the production line. The management of the factory ascribed all the increase in productivity indicators to the increased use of the factory's high-speed airjet looms, because, although they use the same number of machines and produce the same type of fabric as they did in 1978, they have increased machine productivity (meters/machine hour) by 12 percent and labor productivity (Yuan/employee) by 23 percent, which has allowed the factory to almost double its annual profit over the five-year period.

2.03 The success of the No. 6 Factory in Shanghai has prompted many other enterprises to build such systems. In Shanghai alone, it is estimated that 10-20 plants have installed or are planning to install such systems. The No. 6 Textile Factory has helped install such a system in another plant, and is also in the process of preparing a project to expand the application of computers to five other processes, namely warp preparation, starching, preparation (reeding), weaving, and quality control.

2.04 The use of modern electronic control systems can also play an important role in improving the energy efficiency of Chinese industry. For example, China has about 200,000 industrial boilers which consume about 100 million tons of coal equivalent annually. Clearly, improvement in efficiency of these would have significant economic benefits. Although the theory of optimal control has been around for some time, the inability of existing control systems to measure or obtain precise information regarding the operating status and to process that information in "real-time" led to very conservative operating procedures, since reliability is extremely important in industrial processes. Modern control systems using microelectronic devices make it possible to optimize system performance without sacrificing reliability, and can lead to major energy savings--one estimate was that five million tons of coal could be saved annually, in China, by improving the efficiency of large boilers alone.

2.05 There are also many technical and economic advantages to using microprocessor-based control systems in machine tools, material-handling machinery, and equipment used in process industries (for instance, chemicals). These advantages include increases in the range and variety of performance available from a capital good, better ability to tailor hardware, and components to meet different users' specific requirements. Further advantages are efficiencies in operation which arise from replacing hardware with software and the possibility of making subsequent improvements by simply changing the stored programs, as well as the considerable increase in productivity possible in the design and manufacturing processes. In addition, well-designed electronic systems using integrated circuits are, in general, significantly more reliable and much easier to use.

2.06 In spite of these advantages, which are applicable to both developing countries such as China and industrialized nations, it is fair to note that the diffusion of microprocessor-based innovations has been slower than originally expected, even in Western countries such as Great Britain. The reasons for this are both technical and economic; and an examination of them is useful for understanding the constraints China faces in its effort to reap the benefits of electronics technology.

2.07 Perhaps the most obvious constraint is the availability of suitable technology. Although China still has to go a considerable distance before it can commercially produce the heart of such electronic systems, namely the microprocessors and the requisite supporting chips, the technological constraint is less important for these components because they can be imported fairly easily and at lower costs than China could expect to produce them over the next few years. The problem lies in the know-how for using them. More specifically, it is the technology of transducers, sensors, interfaces, and necessary software that is lacking. Secondly, there is a lack of understanding (not just in China) of the processes to be controlled. For example, potential users may not know which parameters have to be controlled or how they can be controlled.

2.08 The Chinese economic system has traditionally suffered from weak links between enterprises, particularly in enterprises under the jurisdiction of different bureaus or ministries. This makes developing micoprocessor applications more difficult because success is usually based on close interaction of enterprise personnel who are thoroughly familiar with the process to be controlled or the manufacturing technology of a product, and those who design electronic systems. The Shanghai Boiler Factory provides an illustrative case. This factory, which is one of the largest in China, produces three series of large boilers for power stations and high-pressure vessels for chemical plants. Their largest boiler is a 300 MW one-through type (that is, without any drum) which was designed by the factory over a five-year period (1967-72) and first manufactured in 1974. Although a boiler of this design is cheaper to manufacture than a drum boiler, it appears that the factory is unable to integrate modern advanced control techniques with the design and is, therefore, unable to meet the demand of electric utilities for energy-efficient systems. The enterprise signed a contract with a foreign firm to produce an equal-size drum boiler, because the licensor was able to supply the required control system. Although the factory proposes to design new once-through boilers, based on their experience and learning with the licensed design, by February 1984, they had still not organized the necessary software development. The factory management presumed that their parent ministry would do so but it was clear that, if indeed this was being done, the involvement of the factory itself was minimal.

2.09 The above case exemplifies another constraint to the development of microprocessor-based innovations, namely the lack of specialized manpower. The skills required are in short supply, even in countries that have many more designers and engineers. Consequently, China, which saw its higher education system disrupted for ten years until the mid-1970s, faces an especially severe problem with its shortage of educated and experienced engineers. Another factor specific to China is the virtual absence of application engineers in the manufacturing sector. This has its roots in the past economic system when enterprises were not responsible for sales of their products and had little incentive for engaging in sales and application engineering. It is worth noting that the success of firms pioneering new technologies such as micro-electronics or plastics has, in the United States, depended a great deal on their providing application engineering support to their customers. Besides facilitating marketing, an important by-product of such a business strategy has been its function in identifying user needs.

2.10 The lack of in-house engineering skills may, of course, be overcome by the use of external consultants. The engineering consultancy services sector in China is still in an embryonic stage and, given the system of manpower allocation, together with the shortage of electronic engineers and computer specialists, it is doubtful whether this avenue will be open without an explicit effort by the government. It is also doubtful whether part-time consultants based in universities and research institutes can fulfill all the key requirements of design and manufacturing know-how.

2.11 The development of electronics technology requires certain special features in the support services infrastructure. This is partly related to its novelty and partly to the intrinsic nature of the process involved. Unlike mechanical processes, electronic phenomena are not as readily observable, due to both the miniature elements and the physics involved. Consequently, specialized equipment and skills are necessary for testing and maintenance. Software components also have their own peculiar characteristics due to their intangible nature. Thus, unlike mechanical gadgets, it is virtually impossible to take an electronic system apart and visually inspect for defects or make improvements. Besides the well-known software "bugs," typical problems with electronic systems and components include radio frequency interference, static interference, fragility, and temperature stability, all of which require specific training and experience to identify and correct.

2.12 The major driving force behind microprocessor-based innovations is undoubtedly the dramatic decline in cost of information-processing capabilities, but it would be a mistake to deny the significance of financial resources in the development of this technology. Although the microelectronic elements may, themselves, be very cheap (which, incidentally, in China they are not), the total costs of an electronic control system may be substantial. The cost of other components including peripherals and interface equipment and manufacturing costs including testing and quality control, development, and engineering expenses can be very high and especially so for software.

2.13 An enterprise seeking to incorporate microelectronics in its products or in its process equipment faces significant expenditure both in development and engineering and in capital investment. The need for transducers (sensors and actuators) has been mentioned earlier--these are rarely available off the shelf in China, and have to be developed. Similarly, mechanical and electronic interface has to be specially designed for specific applications, to overcome "bind" in mechanical parts, for instance. Finally, although retrofitting is sometimes possible, the whole mechanical design usually has to be redone, and greater precision is needed in the manufacture of mechanical parts.

2.14 The last set of activities explain why a large part of the effort for the development of electronics technology for the industrial sector is best undertaken under the control of user industries. For example, the usefulness of an electronically controlled, automatic spot welder depends upon the quality of the weld produced and not on the sophistication of the control algorithm. Consequently, the best judge of the benefits and, therefore, of the nature of the development effort is either a welding equipment producer or user. Such a focus of decisionmaking, together with the resource (financial, human, and material) requirements for technology development, points to the importance of economic policies discussed below and institutional structure covered later, which influence the demand for technology and its supply.

2.15 The first policy concerns incentives for undertaking the effort for development of microprocessor-based innovations. Since this issue is dealt with extensively in <u>China: Long-Term Issues and Options</u>, only two illustrative examples will be cited. We have mentioned the possibility of energy savings through the use of advanced control systems. Given that the incorporation of such control systems is not costless, a manufacturer of boilers would develop these if he could charge a price that would offset the additional expense. Alternatively, a user would demand or add a system if the savings were greater than the additional cost. In either case, if the cost of energy is lower than its opportunity cost, it is possible that a socially beneficial innovation will not be adopted. Similarly, on-line process controllers can reduce raw materials consumption in industries as diverse as chemical manufacture and sheet metal stamping. Their adoption will also depend upon the incentives to conserve raw materials, which in general will be a function of price and availability.

2.16 Besides real-time industrial control, the Chinese Government is also seeking to popularize the use of microcomputers in enterprise management, based on its conviction that improved management will lead to economic benefits through improved efficiency of operations such as material flow and inventory control. It has been reported that Liaoning province, for example, has decided to grant interest-free loans to all factories for the purchase of microcomputers. Such a policy will, no doubt, provide some incentive to the enterprises to acquire such systems, but various reports of inadequate utilization of computers in the past indicate that it may be necessary to reward improvements in efficiency to ensure the economic benefits of using computers are realized. There are indications in some industrial sectors, for example, that inventories are excessively high which ties up (working) capital resources. To the extent that this is encouraged by a low cost of capital resources, it is doubtful whether the use of microcomputers is going to improve matters significantly.

3. LEVEL OF TECHNOLOGY

3.01 Much of the discussion on upgrading industrial technology is centered around the level of technology, where the "level" is usually measured in terms of the vintage of the technology in industrialized countries. While it is often true that newer electronics technologies offer greater economic benefits than older ones in these countries, it must be recognized that they do so within the context of factor prices, infrastructure, and technological capabilities which are very different from those in China. For example, due to the high cost of labor in Western countries, automated soldering technology leads to lower cost of production for electronic assemblies. Clearly, this may not be true for China because the wage rates (and the opportunity cost of labor) are much lower and an economic case can be made to continue with older technologies which are more labor-intensive.

3.02 It is necessary that such decisions on choice of technique are based on sound economic analysis rather than on prior assumptions because, even in China, automated soldering may be economically more efficient. For example, the poorer reliability of manually soldered subassemblies may be unacceptable for many electronic systems and products. Even if such subassemblies are used (often because there is no ready alternative), the net economic benefits after accounting for the various elements of lifetime costs may be lower than those of automatically soldered subsystems. Clearly, the choice of technique for a a process or production stage should depend upon the specifics of the situation and must be one of the key considerations in detailed project design and appraisal.

3.03 Another aspect of the level of technology is its absorption or digestibility, both for the production techniques and the products manufactured. This may be illustrated by semiconductor memories. Currently, China produces 1K and some 4K dynamic random-access memory (RAM) integrated circuits. In industrialized nations, the standard is 64K, with 256K chips becoming increasingly available commercially and 1M dynamic RAMs are being developed. What should China's policy be regarding 16K dynamic RAM technology? Is it an appropriate level of technology?

3.04 One view is that this technology is obsolete or outmoded and China should not sink any resources into acquiring it. An alternative view is that 16K dynamic RAM is a significant enhancement over China's present production capabilities and users need denser memory chips than those presently available. Some proponents of the first view argue that the improvement in technological level is not large enough and rather than creeping along behind the West, China should leapfrog ahead in a determined manner. As for users who need larger memory chips in the near future, these people argue, they can be easily supplied through imports. A third view could be presented which argues that memories are a low-margin high-risk business and China would be well advised to stay away from their production altogether and to import all its requirements.

3.05 There is some truth in all of the above assertions, despite their seemingly irreconcilable nature and, in order to address the original issue, it is necessary to pose an ancillary question, namely, for what purpose or to what end? If the objective is to supply domestic users with memory chips of large capacity, it is doubtful whether Chinese enterprises could supply them, especially the 64K and above, at a lower cost than imports, over the next several years. There may, however, be a significant demand in China for 16K chips over this period, given the present status of computer technology and, since developed country producers may be expected to discontinue production of such chips, production in China may be economically viable. On the other hand, it may not since prices for 64K and 256K RAMs can be expected to drop substantially.

3.06 The decision may then depend upon externalities. Analogous to the demand for 16K dynamic RAMs is the demand for large-scale integrated (LSI) circuits and for custom chips, and this demand is substantial in China. Yet, Chinese process technology for integrated circuits lags considerably behind industrialized countries which are now moving toward very large-scale integration (VLSI). Thus, although memory chips may be "low-margin" products, they may play an instrumental role in the development of LSI technology in China, especially in view of the process control problems afflicting the semiconductor manufacturing industry. This is because many practitioners/manufacturers regard RAM production as an instrument for acquiring both design and production know-how, as well as some investment capabilities. RAM chips are easier to design and by their very nature are more amenable to statistical analysis (of defect ratios, for instance), providing a diagnostic aid in improving process technology through determination of optimum temperature, timing, and duration of process steps, line widths, and spacing, etc. The production of simple memories can also provide valuable experience to the engineers and technicians in the use and maintenance of complicated automated process and test equipment as well as in packaging technology.

3.07 16K RAMs represent the highest capabilities that present-day Chinese technology can aspire to because essentially the same techniques for production (for instance, lithography) and design principles are used in smaller memory chips such as those currently made in China. Thus, part of the justification of 16K RAM production lies in the large gap between current yields and those that have been attained elsewhere in the world. As far as the next generation of technology, VLSI, is concerned, the know-how acquired through 16K RAM technology would serve only as a base for substantial further development, especially for acquiring capability with totally new techniques such as electron-beam lithography and dry etching.

4. LEARNING-BY-USING

4.01 Learning-by-using is perhaps the most neglected part of the process of acquiring technology in much of the discussion on industrial technology development. As the term implies, it refers to the accumulation of knowledge through the use of a new product or process. For a variety of reasons discussed below, it is relevant to the development of electronics technology. Unlike learning-by-doing which has been a cornerstone of China's strategy for acquiring technological capabilities in the past, learning-by-using is an area where the systemic constraints to the development of industrial technology in China may be the most profound and to which Chinese authorities may wish to give explicit policy attention in the future.

4.02 Many products manufactured and processes used in modern industry, especially electronic devices and systems, are too complex to be designed perfectly the first time around and only after extended use can they be improved. The knowledge gained may be "embodied," that is, exclusive to the product or process in question and may be used to redesign or improve it, or it may be "disembodied" in which case the knowledge gained can be used to operate the product or process better or applied to other products or processes. It is important to note that the phenomenon of learning-by-using is not confined to field trials for the introduction of a new product, but continues well into the maturity phase of the product cycle.

4.03 Rosenberg (1982) provides two examples of learning-by-using in the electronics industry in the fields of software and telecommunication systems. Given the importance of user convenience in software and the near impossibility of producing an absolutely bug-free system the first time around, successful software development is predicated on close interaction with the users even for application packages sold over the counter. Similarly, in the telephone industry, electronic switching systems in the United States could only be perfected after the new system had been put into operation and allowed to handle real telephone traffic. For personal computers, the feedback from users is no less important in the design and engineering of new products than in semiconductor technology.

4.04 In consumer electronics, it is possible to cite an example from China itself. A few years ago, users found the picture quality of one of the models produced by the Wuhan Television Factory to be poor. The source of the problem was identified, by a repair shop, as being in the audio system. From this knowledge, the factory was able to modify the design. Other feedback obtained from their users allowed the Wuhan Television Factory to identify several areas for improvement, in both external and internal design, such as the need for reception boosting for the rural areas in Hubei province.

4.05 It appears that such happenings are more of an exception than the rule, in China. One reason, of course, is that, until recently, "sellers' markets" prevailed for most industrial output of consumer durables and industrial products. This provided little incentive for producers to identify users' problems and concerns. In any case, producers did not have marketing responsibilities. While economic reforms are expected to alleviate some of these problems, it is not clear whether they will overcome prevailing attitudes engendered over several years, to promote adequate interaction between industrial producers and users.

4.06 The problem may be significant between producers and users of capital goods such as process machinery. Chinese enterprises have a tradition of developing, improving upon and producing a large part of their own production equipment. Many foreign observers have noted evidence of innovation at the shop-floor level. The problem in China is not that such learning-by-doing does not take place, but rather than individual learning does not transform itself into social learning. In other words, the technological improvements or developments do not feed back to the manufacturer of the equipment if it is external to the enterprise, nor do they diffuse readily to other enterprises using similar equipment. Together with the premium placed on "self-reliance" even at the enterprise level in the past, this lack of feedback leads, at best, to excessive duplication of applied research and engineering and, at worst, to no advance in the state of the art in the industry as a whole, thereby perpetuating its technological dependence on external sources.

4.07 In studies of technological innovation in three product groups of US industry, namely electronic subassemblies, semiconductor manufacturing and scientific instruments,[2/] it was found that most of the innovations in process machinery were "user dominated." Not only did the user articulate his needs, but he also did all of the research and development (R&D) up through the construction of the first prototype. After that, it was the manufacturer(s) who did the product engineering for serial production and who commercialized the products, thus providing a severalfold multiplication of the innovations'

2/ Von Hippel (1976, 1977).

economic benefits. Product engineering by the machinery producer often leads to further improvement in terms of reliability, manufacturability and convenience of operation. Specialized manufacturers are also able to reduce the costs of implementing innovations due to their experience with manufacturing technology and the economies of scale and specialization.

4.08 It is for these reasons that, in Western countries, very few semiconductor manufacturing firms now make their own production equipment, but they do maintain close relationships with suppliers. In China, there appear to have been two extremes and the situation is changing only slowly. On one hand, specialized equipment is produced in-house by the user. Besides the high costs induced by custom production of equipment that could be produced in larger quantities, the disadvantages include duplication of research, development, and engineering (RD&E) effort, ignorance of state-of-the-art technology and weak horizontal diffusion to other enterprises. On the other hand, there is virtually no continuing relationship between the equipment supplier and the user, the latter being responsible for all repairs and maintenance. Here, there is very limited scope for learning-by-using for the equipment manufacturer.

4.09 Another aspect of learning-by-using concerns feedback from users of a technology to R&D personnel engaged in design and development of the technology. We have noted earlier that visitors have often observed shop-floor innovations in enterprises, but in knowledge-intensive, technologically sophisticated sectors such as electronics, these must be limited in scope unless they are supplemented by adequate scientific analysis. There are some indications that in the fabrication of semiconductor devices, for example, Chinese enterprises may be attempting to do things beyond the capabilities of their existing technology. The industry requires monitoring of problems occurring under actual production conditions that call for further research, best done in universities or research institutes, but not being undertaken because research personnel are not aware of them.

5. SECTOR PLANNING

5.01 The importance of sector planning for the technological development of the electronics sector cannot be overemphasized. This is because the electronics sector comprises a variety of activities, widely different in terms of their economic and technological characteristics. These are the nature of products manufactured and inputs used, end-user markets, factor intensities of the various techniques of production, and the technological expertise required. Until now, China has attempted to develop almost all segments of the electronics sector which may have diluted its efforts with poor economic results. In view of its limited supply of human and financial resources, it would seem appropriate for China to be more selective and to try to obtain the maximum economic benefits on the basis of its long-term, dynamic, comparative advantage.

5.02 It should be noted that sector planning is qualitatively different from project appraisal; sector planning is really a prerequisite for proper appraisal of projects whether they are concerned with investment for production or with RD&E. This is especially true of the electronics sector which is characterized by many complementarities and links between different parts of the sector itself and other industrial sectors. In view of the importance of learning-by-doing and learning-by-using, together with the anticipated changes in human and material resources in the next decade (as skilled engineering personnel are further educated and trained), it would be useful to chart a time path for the future. Thus, good sector planning allows initial areas of concentration to be selected, as well as a logical sequence of activities based on existing and foreseen technological capabilities, availability of resources and industrial infrastructure.

5.03 Planning should be viewed as an iterative investigative process. In other words, it should form an interactive framework for detailed project appraisal instead of substituting for the latter. In a technologically dynamic sector such as electronics, sector planning should be used to build flexibility into the development strategy rather than to drive the sector along a narrow path which may turn out to be inappropriate in the future. It is clearly beyond the scope of this paper to undertake a sector planning exercise for China's electronics industry. We confine ourselves to a brief review of some considerations which are particularly relevant from the point of view of technology development.

5.04 Perhaps the basic question is which industrial activities in the electronics sector should China pursue? For what products among the many possible end-user items and intermediate goods should China acquire or upgrade production technology? The importance of current demand and future needs is self-evident because production of large quantities allows economies of scale in manufacturing. Moreover, in certain segments of the electronics sector, especially semiconductor fabrication, there is clear evidence of cost reduction in the manufacture of individual chips due to experience with production. Not only are the investment and development costs spread over a larger volume, but also the variable costs decline due to an increase in productivity of both labor and capital. The concept of the learning curve is so well entrenched in the folklore of the Western electronics industry in that it is an essential ingredient of business strategy of most corporations; China could gainfully employ it in its sector planning.

5.05 The markets to be considered must also include export possibilities. Several developing countries, primarily those in East Asia, have advanced their electronics sectors by focusing primarily on export of electronics items, starting with the more labor-intensive processes, such as assembly, and then broadening the base. For a variety of reasons, such as the technological trends of increased automation in all stages of manufacture, increasing levels of integration in components and systems, and the economic trends of an increased number of suppliers and growing protectionism in many markets, the traditional path followed by the other East Asian exporters may not be open to China. By following a path based on using the large domestic market to develop technological capabilities, China could probably emerge as a significant exporter of several electronic goods.

5.06 Most electronic products are systems composed of many different parts, components and subassemblies whose technologies are very different, but these same components and technologies are used in many different products. For example, a microcomputer system contains parts as different as printed circuit boards, various integrated circuits, precision-engineered mechanical and plastic parts, a power supply, a cathode ray tube (CRT), motors, magnetic recording heads, magnetic media for disks, and so on. CRTs and printed circuit boards are also used in TV receivers. This fact has several implications for technology development, in particular, and sector planning, in general.

5.07 First, there is a need to ensure the availability and quality of all components and subassemblies--a problem with even one means the whole system is often inoperative. It is also necessary to maintain a broad technological balance between different parts, as well as with the manufacturing technology, including testing and quality control, because a system is only as good as its weakest component.

5.08 Sector planning should also attempt to capitalize on the economies of scale and specialization. This pertains not only to the decision whether to import a product (final or intermediate) or to produce it domestically, but also to the division of labor within China and within provinces or municipalities. China has a large number of small factories, many of which are poorly equipped for the production they are engaged in. Recent press reports give the impression that the proliferation of enterprieses is continuing and that all the provinces are attempting to hop onto the electronics bandwagon. There is clearly great potential for scarce investment resources to be wasted through unnecessary duplication in capacity, and for certain critical gaps to occur. The governmnent clearly recognizes this and, presumably, the current emphasis on upgrading existing factories rather than investment in new greenfield plants is a reflection of its concern.

5.09 It should be recognized that upgrading all plants may not be beneficial, especially if it is done in a haphazard manner. Given the demanding requirements of several critical processes in modern electronics industry, there may be a need to establish some new facilities, though it is expected that the share of this in the overall upgrading effort will be relatively small. Essentially, the sector planning effort should be like the restructuring strategy of a multidivisional corporation. This is where the various units of a firm are physically and organizationally restructured to provide better matching of unit capabilities to the functions they perform, to support the overall strategy. An example of such an effort in another sector in China is the preparation of the proposed Machine Tool Project in Shanghai, supported by the World Bank.

5.10 Standardization is also essential. It benefits technology development in electronics and in all modern industrial sectors. It makes design of systems and components much easier, enables modifications in system design to meet custom needs, permits quicker repair and maintenance, and reduces the burden on technological infrastructure through the reduction of inventory costs.

5.11 Sector planning should also aid explicit accounting of externalities induced by being able to transfer various skills from one product line to another in electronics-related industries. One reason Singapore is successful in the production of computer peripherals (such as disk drives) is its capabilities in machining and instrumentation. Similarly, the Republic of Korea, which has accumulated significant production and investment know-how in the manufacture of TV receivers and CRT technology, is well-placed to transfer this to the production of data display terminals. It would thus appear that, contrary to some common perceptions, the manufacture of consumer electronic items and assembly and testing of even some simple systems allows both the deepening and broadening of relevant skills which can be used for the production of more sophisticated goods.

5.12 While integrated circuits and associated technology are undoubtedly going to play an increasing role in the electronics sectors of all countries, it is not clear whether the skills developed in assembly operations are easily transferred to other activities because the technology involved in the bonding and packaging stages bears little relation to others in the electronics sector. On the other hand, semiconductor production, skills relating to process technology, design, debugging, and testing at various stages of one product line (memory chips) are transferrable to others (microprocessors).

5.13 Of course, there are many skills that have wide application both in the production and in the use of electronics and computers. Such generic skills include digital logic design and troubleshooting, software programming, equipment maintenance and repair, and testing and quality control. Since they currently pose a major constraint to the development and diffusion of electronics technology in China, one function of sector planning should be identifying critical needs, perhaps on a regional basis, and devising suitable training programs.

5.14 The physical counterpart to these generic skills--the industrial infrastructure--is another issue in sector planning. As in most modern industry, electric power is a critical requirement for all parts of the electronics industry. The planning exercise could lead to the formulation of investment programs for electronics complexes or, alternatively, could identify locations where the infrastructure constraints are not binding. For example, since the television industry is relatively space-intensive, it may be appropriate to locate future expansion in well-designed, uncrowded facilities in regions where land is not at a premium. For efficient operation, adequate power, communications and transport facilities would be necessary, especially given the difficulties of transporting bulky and fragile CRTs.

6. ACQUISITION OF TECHNOLOGY

6.01 Just as considerations of existing technological capabilities, industrial infrastructure, and availability of complementary inputs are important in choosing the activities and technologies for development, the equally critical choice of how the required technological capabilities are to be acquired will depend upon such factors as well. The diversity in the electronics sector suggests that there is no method that is optimal across the board; it will, in each case, depend upon the availability of the required technology. For example, in certain electronic systems, a foreign enterprise may be willing only to participate in a joint venture and be unwilling to license other proprietary elements.

6.02 Although electronics is one sector where China's need to obtain technology from foreign sources is most obvious, it must be emphasized that the dichotomy between importing technology and developing it locally should not be carried too far, since experience in both developed and developing countries has shown them to be complementary. Indigenous efforts at upgrading technology, if not a prerequisite, do contribute to realizing benefits from imported technology that are greater than those possible without such efforts. Conversely, imported technology can enhance the efficacy and efficiency of local activities in industrial technology development.

6.03 The many different schemes possible for importing technology may be categorized as licensing, capital equipment imports including turnkey installation, engineering services, foreign investment including joint ventures, foreign training, and reverse engineering. Each of these methods has its own features whose interaction with the technological characteristics of different parts of the electronics sector translates into specific advantages and disadvantages for China.

6.04 Licensing may itself be divided into two categories--product design and process know-how. Licensing a product design makes sense only if the licensee already has the manufacturing know-how and can make use of the design. Thus, for China, it would make little sense to license IC designs until it has upgraded its semiconductor processing technology. It would probably make more sense for certain systems (TVs, telecommunication equipment) to be assembled in the country though, once again, it may not make sense to expend financial resources to buy designs/licenses for modern products unless it is clear that their production can be organized efficiently. A disadvantage of both product and process licensing that is often cited is that firms are only willing to license obsolete technology. While this is probably true, it would appear that to the extent that such technology is economically efficient in the Chinese context, it should not be a disadvantage. Perhaps a more fundamental disadvantage relates to the fact that licenses only transfer codified technology, which is a small part of the requisite design or process know-how. Sometimes, a technology license also includes the supply of certain critical inputs or proprietary components by the licensor and unless these can be obtained locally or alternative sources can be found, this may lead to undesirable dependence and exploitation. Nonetheless, there is one big advantage to licensing, and that is relatively quick access to certain technology that can create significant downstream benefits, for instance, electronic control systems for machine tools.

6.05 Importing capital equipment provides access to embodied technology and, in many cases, importers have found this to be the only way of transferring a particular technology. For many processes in the electronics industry (semiconductor fabrication, testing functions, etc.), equipment suppliers have often had close relationships with users and are very knowledgeable on the subject, including understanding the underlying reasons for various functions. As the Chinese have learned from their early experience with importing technology, the danger with this mode of acquisition is neglect of the complementary know-how needed not only to run the machinery efficiently, but also to adapt it to local conditions, maintain, repair, and improve upon it.

6.06 A special case of capital equipment imports that can minimize the time and effort required initially to go into production is the importing of turnkey plants. To maximize the degree of knowledge transfer, Chinese enterprise personnel should participate in the installation, especially in technologies where substantial expansion is envisaged for the future (TV assembly lines). This would help build the technological capabilities needed to design and implement investment projects. In any case, it is essential in all capital equipment imports to include training of Chinese engineers and technicians in the agreements.

6.07 One mode of acquiring foreign technology which has probably received less attention than it deserves, in China, is the use of technical consultants. In a knowledge-intensive industry like electronics and especially in the least-understood processes like wafer fabrication, experts can provide valuable services in upgrading technology across the whole spectrum of R&D, design, processing and testing. The use of such people would appear to be the ultimate form of unbundling a technology and, theoretically, a team could be assembled to meet the specific needs of an enterprise or project. The problem with this course lies first in guaranteeing the quality and expertise of the engineers and technologists and, second, in planning their program and focusing their efforts in an integrated manner. It may be a good idea for enterprises to build long-term relationships with consultants to ensure availability when needed and to have them monitor worldwide trends.

6.08 Foreign investment, especially in the form of joint ventures, can provide access to several modern electronics technologies that may not be otherwise available. Such enterprises also offer the opportunity for acquiring, over an extended period, production and R&D management skills that are especially relevant to the Chinese electronics industry, particularly for material handling, quality assurance, and process and environmental control. One disadvantage of this method is that the foreign partner retains significant control over technology questions; other advantages parallel those for licensing.

6.09 Educating and training Chinese engineers and scientists abroad can play a significant role in expanding the knowledge base for the long-term development of electronics in China. It may be difficult to arrange for industrial experience for these technologists unless it is linked with other modes of technology acquisition such as the importing of capital equipment or joint ventures. This is why foreign education is more appropriately viewed as a means for strengthening the science and technology infrastructure than as an instrument for acquiring specific industrial technologies. The benefits of foreign experience will only be realized if industrial enterprises and research institutes are able to use these people, especially to implement new ideas they have learned or generated. It must be noted that in a rapidly advancing field such as electronics, knowledge becomes out of date and, in order to benefit from the investment in education and training, periodic updating or replenishment is necessary.

6.10 In the past, China has attempted to make extensive use of reverse engineering to acquire technology in electronics as well as in other sectors. Although reverse engineering, which should be distinguished from copying, has a fairly long tradition in the electronics sector even in developed countries, it may have limited usefulness for China's current needs in electronics technology. It is useful as an educational or training mechanism, especially for acquiring design technology because it allows a gradual understanding of the reasons for a product's design. As a means of acquiring production or investment know-how, it is probably too slow, too expensive, and too risky--several Chinese enterprises have reported failures with reverse engineering for both products and production machinery. With electronics systems, it is becoming more difficult with increased circuit complexity and miniaturization, and the rise in importance of software and firmware.

6.11 In conclusion, it is worth noting two points about technology transfer. First, the advantages and disadvantages of the above means of acquisition are often overshadowed by unsuitable institutional environments and inadequate infrastructure. There is no point in trying to acquire an advanced technology (LSI/VLSI fabrication, for instance) if it cannot be used due to lack of clean room facilities, deionized water, or pure gases. Second, the choice of source or partners can be crucial to success. Clearly an entity, especially if it is a private corporation, is not going to transfer technology unless it suits its own objectives, whether by obtaining monetary income from the sale of technology or by associated business interests. In the area of electronics, two types of firms from Western countries may merit more attention than has been previously accorded. One category is small firms that have access to know-how but are short of capital for production. The interests of these firms may be congruent with those of Chinese enterprises since they would be less concerned about competition.. A variant of this category is firms desiring second sources for their products to improve the marketability of their products, especially for integrated circuits. The second category of firms are those which may be willing to transfer know-how in certain areas in the interests of seeking markets for different products they want to sell (not necessarily critical inputs into transferred technology). An instrument manufacturer may, for example, be willing to license some technology because it establishes the manufacturer's presence in the Chinese market and allows it to expose its other lines of production.

7. INSTITUTIONAL STRUCTURE FOR TECHNOLOGY DEVELOPMENT

7.01 In China, where the pattern, direction, and level of technological effort in industry is still essentially molded by the planning process, electronics has been designated a priority area by the highest levels of government. The Sixth Five-Year Plan decrees that this sector will be a major recipient of national funds for technical transformation and 550 electronics projects have been chosen for technical renovation. Although the response to this call for mobilization of resources has been significant at all levels of both the industrial and administrative hierarchies, it must be pointed out that there are major limitations to "top-down" flow of information. The biggest difficulty arises because such instruments have a tendency to concentrate resources in a "technology-push" effort rather than on need, or "demand-pull" innovations. Elsewhere in the world, the electronics revolution has been fueled by entrepreneurs perceiving or anticipating needs and racing to fill them.

7.02 This is not to deny that centrally directed or coordinated efforts have an important role to play, but rather to point out that their scope for effectiveness in the electronics sector is narrow and generally confined to a few strategic (often defense-related) areas requiring a very large-scale effort and quantum leaps (Japan's Fifth Generation Computer project and possibly the VHSIC program in the United States). Even if China opts for this approach in defense-related electronics, it should be aware that, given its shortage of human resources in particular, there is a danger of "crowding out" or severely distorting and limiting the economic payoff of the civilian technological effort. This may not be compensated for by the spin-offs from defense research. In China's civilian industries, the planning-generated demand for specific technologies may be more relevant for certain subsectors such as steel, heavy machinery or large-scale process industries, especially because what is often termed "planning" in China is really a project review and selection process. While there is clearly national research planning coordinated by the State Science and Technology Commission (SSTC), there is little technology planning of direct relevance to industry. Thus, it may be true that for a relatively dispersed sector such as electronics, the system is unable to reap the benefits of sector planning described earlier and may be functioning as a cumbersome bureaucracy with debilitating effects on technological development.

7.03 This is supported by the story of the DJS-186 computer which has been published elsewhere.[3/] Briefly summarized, the history runs as follows: the decision to develop this system was taken in 1978, but the prototype work

3/ Sigurdson & Bhargava (1983).

was not completed until early 1983. The elapsed time of five years is much longer than would be required in an industrialized country for a computer of similar complexity. There were several reasons for the delay, one of which was the sourcing of components, though the system is now going to use imported chips anyway. More importantly, there were delays in selecting the enterprise to mass-produce the computer; as late as May 1982, the institute that developed the system did not know who it would transfer the prototype to. Clearly, the product engineering and subsequent commercialization will be much more costly because the interaction between the developer and the producer has been so limited.

7.04 The case of the DJS-186 computer also points to inadequate links, in China, between research institutes which are responsible for applied research and the enterprises which are the locus of most product development. They are weaker still for entities further upstream in the research system such as institutes under the Chinese Academy of Sciences whose work seldom gets translated into industrial applications. The links are also weak among enterprises, especially if they are under the jurisdiction of different bureaus or ministries. For example, Shanghai No. 6 Textile Factory, mentioned earlier, has very little support or interaction with the enterprises and institutes of the Ministry of Electronics.

7.05 Interestingly, for reasons based in China's political history, universities in China are active in some industrial work, especially in electronics, and some of them produce components. Qinghua University is reported to be a producer and supplier of integrated circuits to industrial users. Such activities probably fulfill several worthwhile national objectives including providing supplementary training for students and faculty, but it is doubtful whether they can really advance the state of the art in China; for example, the quality of the components produced at Qinghua is reportedly not much better than those in other small factories because it is as poorly equipped (for instance, no rigorous environmental controls) as the factories.

7.06 In recognition of many of the difficulties cited above, the Chinese authorities have implemented, or are in the process of implementing, a series of reforms in the science and technology system. The basic thrust of these reforms is to forge closer links between research institutes and production enterprises through contract research, remunerated consulting services and joint teams for some development work. Research institutes are also expected to generate more of their resources and, within the institutes, a contract responsibility system is being implemented. While these reforms will lead to some benefits for the electronics sector, it can be argued that they are not sufficient to help China make all the advances in electronics technology that it hopes to do.

7.07 The largest weakness in the technology delivery system in China for the production and use of electronics, whether semiconductors, computers, or industrial electronics, lies in applied engineering capabilities. Development must be carried out within, or in close coordination with, industrial enterprises. Applied engineering is qualitatively different from research, though it encompasses some elements of what is often termed applied research. In some ways, it is more akin to absorptive R&D than to creative R&D and is necessary for the assimilation and adaptation of imported technologies to obtain the maximum economic benefits. In industrialized countries, such technological capability resides not only within individual enterprises, but also within engineering service companies who are major actors in the diffusion of technology. In the Chinese context, it is worth noting that the capabilities needed pertain both to human resources and to equipment, especially for specialized services such as production of multilayer printed circuit boards, testing and measurement, and computer-aided design, which are becoming increasingly important for electronics technology.

7.08 An irreversible trend in the electronics sector is for greater integration of circuit elements on single chips; it is precisely this trend that is responsible for continually decreasing costs and increasing functional versatility and reliability. As a consequence, semiconductor manufacturers have to master circuit and logic design technology which means they have to collaborate closely with system designers. Conversely, system designers have to become more familiar with IC technology since design rules frequently change. This is also true of production technology, and system (including consumer electronics) manufacturers have to work closely with chip producers. Thus, together with measures to promote closer vertical relationships, for instance, between research institutes and production enterprises, complementary policies have to be devised to offer greater interaction between electronics enterprises.

7.09 The need for greater links between producers and users of electronics has already been detailed. Since the electronics industry also requires specialized inputs (chemicals for semiconductor fabrication, precision engineering for disk drives), which may not be easily accessible in China, there may be a need to promote greater collaboration with suppliers as well. This would be especially true in the supply of specialized equipment. Even if a prototype of an improved piece of process machinery (such as a soldering machine) is developed for its own use by an electronics enterprise, it would be economically beneficial if a systematic attempt was made to diffuse it to other enterprises, say, by licensing the technology to a machinery producer.

8. SOFTWARE INDUSTRY

8.01 A major constraint on the use of information-processing technology in China is the lack of adequate software. Part of the problem lies in the history of the Chinese computer industry, and its lack of standardization which led to both hardware and software incompatibility between models in the same series made by different factories, and even among those produced by the same factory. Another source of the problem in China is the software for imported systems and the underestimation of its importance in the initial periods of the "open door" policy when the emphasis was on importing hardware. In recent years, the authorities have recognized the crucial role of software in the effective use of modern computing technology and have taken several initiatives to rectify the situation. The focus has shifted onto the development (especially by universities) of application and support software, while the development of system software is increasingly confined to ministry-run institutes and theoretical research is concentrated in the Chinese Academy of Sciences (CAS).

8.02 China also appears to be making a concerted effort to become a significant exporter of computer software. This is evident from a number of agreements being contracted between several Chinese enterprises such as the China Computer Technical Service Corporation (CCTSC) and various multinational companies. There are many economic arguments to be made in favor of China's attempting to export software products and services.

8.03 First, software production is labor-intensive and has recorded relatively low rates of productivity growth in industrialized countries. Consequently, the low cost of easily trained labor endows China with a comparative advantage. Second, there is a large and growing market for software as computers diffuse rapidly in both developing and industrialized nations. Third, compared with many other parts of the electronics industry, the technological and financial barriers to software production are low, and new entrants can be economically viable. Fourth, since the software products and services required are highly diverse and customer-specific, there is greater scope for identifying unfulfilled needs or market niches.

8.04 It would be foolish to suggest that China can easily or quickly become a large exporter of software. India, for example, has the same advantages and more, yet its performance with software exports has belied the hopes and expectations of many observers. The experience of India suggests a few considerations that the Chinese authorities should take note of. One of these is the availability of the required hardware for software development. Not only is it necessary to have systems which are compatible with those in the targeted markets, but also the vintage of the computers used for development is important since it is well known that customers often insist on the development being done on the newest generation of hardware. This means software enterprises should be allowed to update (and upgrade) their equipment fairly frequently, say every 2-3 years. Another factor which is often cited as being responsible for the performance of the Indian software industry is the complex and cumbersome nature of government regulations. Exporting enterprises have to be able to act or react quickly and flexibly to succeed. This includes not only being able to obtain the necessary equipment, services and information, but also interacting with the customers.

8.05 User feedback is very important for software development, which implies an advantage for domestic producers which software exporters have to overcome. Not only is close cooperation required during the development phase, but also software maintenance and support services must be guaranteed to be available, in a timely manner, to the customer. Another disadvantage China faces in some countries concerns language abilities, especially with regard to competitors such as India. One aspect of this barrier that is often ignored is the need for good documentation of software.

8.06 There are other features in the software industry which merit attention, since they imply some difficulties for countries such as China in their quest for greater exports. The most significant one is marketing capability, which is becoming increasingly important as competition heats up. Although this is clearest in the United States for applications packages for microcomputers, perhaps more relevant for China is marketing capability for other types of software. Its present strategy for market entry is to link various multinational hardware manufacturers or software service companies; effort should be made gradually to upgrade and diversify the scope of Chinese responsibilities as more experience and "goodwill" are accumulated.

8.07 In Western nations, small firms appear to be the most efficient and successful in the software industry; in developing countries, as well, it would appear that any economies of scale which exist in this industry will be quickly exhausted at fairly low size levels. Although China's industrial sector has a large number of small enterprises, they generally function in technologically less-advanced activities. If China is to make a concerted effort in the software sector, it will need to devise suitable mechanisms for the growth, stimulation, and coordination of small high-technology-oriented enterprises which can function relatively independently and yet produce to international standards.

GLOSSARY OF BASIC TERMS

Bit: binary digit or basic unit of information (0 or 1).

Byte: usually 8 bits, a second-level unit of information. Storage of one character.

Firmware: software stored on a chip.

Chip: an integrated circuit; sometimes the unpackaged device.

Hardware: the physical parts of an electronic system including electronic, electrical, magnetic and mechanical elements.

IC: integrated circuit; a small semiconductor device (usually silicon) containing many interconnected circuit elements.

K: short for kilo which in computer terminology refers to 1,024 bytes; similarly M (for mega) refers to (1,024)2=1,048,576 bytes.

Microprocessor: a chip containing a whole central processing unit (including arithmetic, logic and control functions) of a computer.

RAM: random access memory; a device to store and retrieve information.

Software: set of instructions or programs telling the hardware what to do.

VHSIC: very high-speed integrated circuits.

VHSI/LSI/MSI/SSI: very large-/large-/medium-/small-scale integration; refers to the number of circuit elements on a single chip.

Wafer: a thin round disc (usually around 3 to 5 inches in diameter) of semiconductor material on which many identical chips are made at the same time.

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