The R&D Process and Technological Innovation in the Chinese Industrial System

Jonathan D. Pollack

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Jonathan D. Pollack

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Rand
1700 MAIN STREET
P.O. BOX 2138
SANTA MONICA, CA 90406-2138

PREFACE

This executive summary documents the principal findings of a Rand project on "The R&D System and Technological Innovation in Chinese Industry." The project is evaluating the following issues based on case studies of the Chinese electronics and metallurgy industries:

- The capability of the Chinese R&D system to meet the equipment and technical needs of end users.
- The capability of Chinese R&D to generate and disseminate technological innovation in products and processes.
- The factors impeding or advancing the innovation process in China.
- The potential role of external assistance in overcoming the bottlenecks in the R&D system.
- China's ability to adapt imported technology to its research facilities and factories.

For findings on the two industries, see:

Jonathan D. Pollack, *The Chinese Electronics Industry in Transition*, The Rand Corporation, N-2306, May 1985.

K. C. Yeh, *Industrial Innovation in China with Special Reference to the Metallurgical Industry*, The Rand Corporation, N-2307, May 1985.

THE R&D PROCESS AND TECHNOLOGICAL INNOVATION IN THE CHINESE INDUSTRIAL SYSTEM

This executive summary describes the principal findings of an in-depth study undertaken at The Rand Corporation on "The R&D System and Technological Innovation in Chinese Industry." As the Chinese leadership seeks to stimulate economic and technological advancement, R&D effectiveness ranks very high among its concerns. The Chinese have long devoted a large share of their technical and manpower resources to research and development, but this historical commitment has proven of limited effectiveness in facilitating the PRC's industrialization effort. The criteria employed in recent years to measure R&D effectiveness (in particular, the effects of R&D expenditure on economic results) have radically reoriented Chinese goals and strategies in industrial and technological development. What are the results to date of these policy changes? Have they enabled Chinese R&D to narrow the gap between research achievements and their application in industrial products and processes? What factors continue to impede this process? And what are the implications of these findings for China's ability to absorb advanced technology from abroad?

To address these questions, Rand made detailed case studies of the electronics and metallurgy industries, based principally on analysis of primary and secondary sources coupled with interviews and field research in China. These two industries bulk very large in the Chinese economy as a whole. Taken together, they account for approximately 11 percent of the gross value of industrial output; they also absorb large quantities of China's advanced S&T personnel. Although there are obvious hazards in generalizing from only two industries, conditions in these large and important sectors are characteristic of present problems throughout the Chinese R&D system. In their earlier years of development, both industries laid far greater stress on output than on product variety, quality, and reliability; both also experienced major difficulties in converting scientific breakthroughs evident in the laboratory to mass production. At the same time, both industries suffered from technological deficiencies that restricted their ability to produce needed items in large quantities.

In recent years, both industries have undertaken serious reappraisals of their long-extant approaches to R&D. In broad terms, these industries are focusing on three long-term goals:

- Both industries are seeking to upgrade their technological foundation, through acquisition of foreign production technology and through accelerated introduction of advanced equipment produced within China. In their purchase of technology from abroad, they are seeking to emphasize manufacturing processes rather than end products.
- With a few notable exceptions, both industries are concentrating on the refurbishment and upgrading of existing facilities rather than the building of new ones, since the replacement of the entirety (or even the majority) of capital stock in Chinese industry represents a far too large and costly route to technological innovation.
- Both industries are seeking to introduce major changes in the criteria employed to measure R&D success as well as provide greater latitude for research and production personnel to pursue needed technological innovation. These steps are intended to increase responsiveness to the needs of end users, with R&D personnel perceiving meaningful incentives for improving the quality, quantity, and variety of the goods and services they produce.

However, the two industries also reflect major differences in their patterns of historical development as well as their present opportunities for technical advancement. Metallurgy has traditionally ranked very high among the priorities for state investment. It is a very large and highly centralized industry, numbering approximately 5000 enterprises and more than 3 million workers concentrated in 13–15 major complexes. Given its capital intensive character, the metallurgy industry remains far more subject to direct central control and supervision. By contrast, the electronics sector is smaller—1.4 million workers in approximately 2600 enterprises—and far more dispersed and decentralized in its research and production.

The pace of technological development in the two industries is also very different. The metallurgical sector generally involves the utilization of far more mature industrial technologies, whereas electronics is in the midst of profound worldwide technological change that has greatly altered industrial and consumer products as well as the economic and societal applications of industrial technologies. The Chinese political leadership has taken note of a "new technological revolution" under way among the advanced industrial economies, in which electronics and information technologies have assumed a central role. In the view of senior officials, China can also participate in this process of rapid technological change, but only by the timely, widespread introduction of advanced electronics technologies into the Chinese industrial system and by providing requisite opportunities for S&T personnel to enhance their research and production efforts. As a result, there has been a major acceleration in demand from consumer and industrial end users for electronics products, services, and applications. At the same time, electronics has been designated a high-priority sector in investment decisions for the Seventh Five Year Plan, scheduled to begin in 1986. By contrast, metallurgy R&D will concentrate on reforming and upgrading existing products and processes and diffusing available technologies more widely within the industry as a whole, even though these steps often entail important achievements in materials utilization and product innovation.

In relative terms, therefore, China's indigenous R&D resources appear more substantial at present in metallurgy than in electronics. The impressive gains registered during recent years in the quantity and variety of metallurgy products seem attributable largely to indigenous R&D capabilities, although the earlier priority to infrastructural investment in metallurgy and the selective introduction of advanced foreign technologies have also contributed to these successes. By contrast, the dependence of electronics R&D on foreign products and processes is everywhere evident, with end users openly soliciting increased assistance and involvement from abroad and frequently bypassing the results and products of their own R&D system.

To more fully consider the implications of these judgments, the project assessed R&D effectiveness in both industries, as summarized below. These evaluations were based principally on interviews and field research conducted in China, supplemented by additional interviews in Hongkong and the United States. Although these investigations involved only a small cross section of S&T activities within the two industries, Rand staff members were able to visit a wide range of research and production units, based on request lists submitted in advance to the host organizations in China. Approximately 80 percent of the units on these lists were visited, lending greater confidence to these observations and generalizations. This sample seems representative of current circumstances in Chinese R&D, but it remains selective, bearing out the need for further research into these issues.

1. How well does the R&D system meet the equipment and technical needs of end users?

Based on published reports from the Chinese and on selected observations during field research, metallurgy R&D has met with qualified but significant achievements in recent years. Important breakthroughs have been scored in product innovation, increasing significantly the number and variety of items produced for industrial end users. These include special alloy steels less susceptible to corrosion and capable of withstanding severe changes in temperature, cold rolling steel production techniques, and a limited manufacturing capability for special steel for oil pipelines. Many of these achievements attest less to the introduction of new production technology than to the continued refinement and improvement of sophisticated manufacturing skills; in a word, successful work with alloys is an art, not a science. These accomplishments notwithstanding, the Chinese remain dependent on the import of various special steels, notably those needed for larger oil and gas pipelines, suggesting that domestic production capabilities are not yet able to meet accelerated demand for selected high-quality products. But metallurgy R&D has demonstrated an ability to move ahead largely on the basis of indigenous manpower and technical resources, reflecting the substantial state investment historically allocated to this sector.

The electronics industry presents a less encouraging picture. Although ministerial-level planners remain convinced that China will be able to meet the demands of end users at all levels of electronics technology, this is a long-term goal rather than present-day reality. The prevalence of foreign products and components throughout the electronics sector attests to the rapidity of technological change on a worldwide basis and the inability of Chinese R&D to keep pace with these changes. Although many R&D personnel in the electronics industry believe that this dependence will diminish once the results of increased state investment begin to be felt, the prospects will very much depend on the ability to procure advanced production technologies from abroad, while at the same time making a major commitment to infrastructural development. The rapid acceleration of demand for advanced electronics products only compounds these problems, since end users exhibit a clear preference for imported items over those produced in Chinese factories.

However, there is evidence of greater progress in consumer electronics than in computer R&D or in the production of more advanced integrated circuits for industrial products. In only half a decade, the Chinese have been able to build a consumer electronics sector where one barely existed in the past. The extremely rapid growth in the production of televisions, tape recorders, and other items reflects the great increases in market demand at the lower end of the technological spectrum. Although these accomplishments have been based principally on the importation of foreign production lines, the growth of a substantial consumer electronics sector also provides some of the critical building blocks for more advanced electronics manufacture, especially as S&T personnel become more adept in the skills and techniques required in more sophisticated electronics production. Thus, an experienced workforce in the consumer electronics sector (for example, those producing linear integrated circuitry) can subsequently turn its attention to more demanding aspects of semiconductor development. It is possible, however, that military R&D retains a proprietary claim on many of the resources in advanced electronics, thereby diminishing the possibility of more rapid breakthroughs in civilian industry. In the absence of firsthand observations, it is impossible to confirm the effectiveness of electronics R&D within the military sector. However, the fact that numerous interviewees indicated that defense electronics has a more immediate claim on advanced production capabilities bears closer examination in future research.

2. How effectively can the R&D system generate and disseminate technological innovation in products and processes?

Throughout the Chinese industrial R&D system, difficulties associated with the interface between the research and production process rank among the most pressing and intractable of problems. This lack of effective linkages constitutes the powerful continuing legacy of the Soviet model of R&D introduced to China in the 1950s. Historically, the gap between these two levels of R&D has contributed to the asymmetries evident between scientific breakthroughs observable in China's more advanced laboratories and the shortcomings of the production process. The Chinese are keenly aware of these problems, and are actively experimenting with methods for reducing this gap. For example, younger generations of Chinese managers are being trained in alternative approaches to management that S&T planners hope will foster increased creativity and initiative on the part of R&D personnel. But the most notable evidence of change is the March 1985 Central Committee decision that calls for a comprehensive restructuring of the science and technology management system. These reforms are intended to greatly reduce the involvement of central planners in the R&D process, reduce the barriers to cooperation across R&D systems, and permit far more latitude for S&T personnel to pursue promising technological paths. However, the scope and ambitiousness of the reforms discussed in the S&T reform document have yet to be matched by commensurate achievements in R&D, attesting both to the newness of the policy changes and continuing uncertainties expressed by research and production personnel alike.

Despite these difficulties, the evidence of new directions in both electronics and metallurgy is incontestable. The reforms work in both directions: offering laboratories and individual researchers new incentives to provide research results to end users, and encouraging production personnel to make greater demands for research results that will facilitate the production process. These policies are intended to overcome the departmentalism long prevalent within the R&D system. When investment and production decisions were a product of a top-down process and when R&D units had no incentives to enhance the quantity or quality of output, communication and collaboration across R&D systems were very poor. Moreover, the wealthier, more powerful units at the more advanced end of the scientific spectrum could remain largely detached from production tasks.

These old arrangements are now undergoing very important changes. Given the concentration of S&T resources in the metallurgy industry in a small number of key enterprises, the immediate opportunities for enhancing collaboration are probably somewhat greater than in the electronics industry. For example, interviewees in the metallurgy field took note of increased efforts to combine research and production tasks within single units and the increased utilization of the Academy of Sciences in ongoing production tasks. Moreover, all the large metallurgical complexes have their own research institutes that are responsible for developing new products. These measures enable the timely concentration of R&D personnel on critical projects and a more direct articulation of demand by end users, making progress on high-priority tasks more likely.

Comparable measures are also under way within the electronics sector. However, there is less of a tradition of such arrangements, suggesting that it may take somewhat longer to achieve equivalent results. Ministerial planners appear persuaded that (in the case of high-priority projects, such as those for microelectronics) collocation of R&D personnel in new development centers is necessary to break down the past barriers to institutional collaboration. Since these arrangements are only now beginning to be established, it is still too soon to judge their effects.

However, new incentives for R&D collaboration among existing units have been instituted in other areas. The emergence of contract research, the new economic inducements for basic research laboratories (especially in the Academy of Sciences) to shift some of their focus to applied work, and the creation of new arrangements for institutes and factories to realize profits from their work are all part of this process. The market opportunities in both electronics and metallurgy—for example, the demand for consumer electronics items and the large profits that can be realized for products using stainless steel (e.g., watches)—offer powerful inducements for R&D units to undertake collaboration when such steps are useful for increasing production and improving product quality. The largest tests, however, will be in shifting from product innovation to new or broader applications for various technologies. In these respects, it is still too soon to judge the effects of the new policies.

3. What factors are impeding or accelerating the process of technological innovation?

The principal factor continuing to inhibit more rapid technological advancement is the powerful legacy of the inherited R&D system, in particular its tendency toward departmentalism, the excessive fractionation of R&D effort, the lack of meaningful incentives for scientific and technical personnel to encourage greater innovation and risk taking, and the poor management and coordination of R&D resources. All have contributed heavily to the shortcomings in product and process development, and some have continued to limit the prospects for technological advance. In the Academy of Sciences and military R&D—the most powerful and advanced components of the R&D system—compliance with the new institutional and managerial arrangements remains uneven. The manpower and technical resources within these areas could significantly affect the prospects for innovation, but only if effective ways are found to increase their contribution to the larger R&D effort. The thrust of the R&D reforms promulgated in March 1985 is very much in this direction—the Central Committee document concedes the lack of well-established, officially sanctioned linkages within the S&T system for coordinating and integrating disparate research, design, and production activities.

Although there are numerous press reports of increased military R&D involvement in the civilian economy (especially the production of civilian items in defense plants and civilian factories utilizing research results transferred from military R&D), firsthand evidence of this involvement (especially the transfer of defense R&D personnel to non-defense tasks) is sparse. In the absence of more detailed information about such transfers, some skepticism is warranted about these claims. For example, it is possible that military R&D is willing to consent to increased collaboration in less advanced technological areas, but not when the technologies in question involve high-priority defense programs. The military is still a very large claimant to R&D resources, and the defense R&D sector appears to be resisting any abrupt shift of its manpower and funding that would impinge too much on military prerogatives.

The principal factor accelerating the innovation process is the rapid growth in market demand for new products. The general economic expansion dramatically evident in recent years has generated greatly increased demand for high-quality products in both metallurgy and electronics. The opportunities for factories to realize profits have begun to reshape the R&D landscape. For example, it is now possible for steel plants to sell a small part of their products, rather than turn over their entire inventory to the state. These developments are even more widespread in electronics, where the availability of consumer items and a major effort to expand the economic applications of such technologies both represent distinct changes. The most enterprising R&D units seem intent on servicing these needs, but their capabilities are stretched thin. The explosive growth in electronics imports attests to the current inability of the Chinese electronics industry to keep pace with demand. But this large gap between supply and demand can also serve as spur to R&D units to shift the orientation of their work. For example, scientists at a leading research laboratory under the Academy of Sciences (which at this time maintains capabilities only for trial production of new products) report that their institute is seriously contemplating the introduction of a microelectronics assembly line. The institute's personnel calculate then their considerable research capabilities could yield substantial revenues if they can shift some of their efforts into the production and marketing of advanced components for the domestic market.

Some of the largest uncertainties, therefore, concern the potential for a further devolution of decisionmaking authority prompted by the acceleration of such market demand, especially in an industry where the pace of technological change is so rapid. For example, certain laboratories and production units may want to greatly expand the opportunities for their personnel to engage in consultancy arrangements or in contracting procedures with other enterprises, but the effects of these new policy developments are still at a very early stage. This conjunction of opportunity and risk is likely to remain a central feature of the R&D landscape for sometime to come, as central planners debate the limits of officially sanctioned R&D reforms, even as the more entrepreneurial R&D units press for greater opportunities for initiative and risk-taking.

4. How can external assistance help overcome the principal bottlenecks that interfere with innovation?

Increased external assistance bulks large in China's plans for technological development. This seems especially true in the electronics sector, where there is a pressing need for foreign technical and advisory involvement and where the Chinese perceive major commercial opportunities for foreign firms. In the metallurgy field, as well, significant investments have been made in the past half decade to introduce advanced technology from Western Europe and Japan, and the selective introduction of newer production technologies seems certain to continue. Indeed, the metallurgy industry has already accumulated a good deal of experience in utilizing foreign assistance to overcome some of the constraints on innovation. As a consequence of the substantial external involvement in previous decades and the relative maturity of the technological base of the metallurgy industry, the internal diffusion of technology (what the Chinese term the "technical transformation of existing enterprises") has become a more important task than a major infusion of new techniques and equipment from abroad.

The picture in electronics is very different. Given the relative youthfulness of the industry as a whole, foreign technologies are essential to the innovation process. At the same time, the tasks confronting the Chinese are as much managerial as they are technological. Continuing shortages in trained manpower have severely limited the utility of foreign technology introduced to China. Increased foreign assistance could therefore prove of inestimable help, both with respect to manpower training and the introduction of more rigorous production and evaluation criteria. But the largest tasks are for the Chinese to solve—eliminating barriers to institutional collaboration, further increasing the incentives for technical and production personnel to innovate and produce, and establishing an environment for increased initiative and risk taking within the industrial sector.

These conclusions suggest that direct foreign involvement (especially in the initial phases of introducing new production technologies) is often instrumental in facilitating the utilization of imported technologies. This judgment is born out by the experiences of firms active in joint ventures. Such involvement has heightened the awareness of Chinese R&D personnel of the more demanding requirements for using advanced production technologies. Although external assistance can facilitate the process of technological innovation, it cannot sustain it. Removing the larger obstacles to improving the results of the R&D process will continue to rest on Chinese shoulders.

5. How effectively have the Chinese adapted imported technology to their facilities and factories?

Chinese planners have announced highly ambitious objectives with respect to acquiring modern technology from abroad. The Chinese stress that technological "closed doorism" will never again be practiced, since this policy would consign China to lag behind the research and production breakthroughs of the industrialized world. Yet the availability of technology is only part of the innovation process. To fully assimilate imported technology, the Chinese must be able to: (1) use such technologies at or near their production capacities, (2) where appropriate and feasible, diffuse production technologies within the industrial system; and (3) be able to adapt and improve upon such production techniques, thereby demonstrating a design capability of one's own.

China's ability to absorb and digest imported technology is marked by some notable successes, but these accomplishments have generally taken much longer than was anticipated. In the metallurgy field, Chinese R&D personnel claim that they have been able to transfer West German cold-rolling techniques first introduced in Wuhan in the late 1970s to the Anshan iron and steel complex. If this report is credible, this would constitute a significant achievement in the ability to disseminate advanced metallurgical technology. Similarly, the Beijing Metallurgical Research Institute reports that it has mastered the use of materials needed to produce the turbine blades that proved so complicating during the Spey jet engine project in the mid-1970s. Such experiences, although gratifying to the Chinese, also demonstrate that effective technology absorption is a prolonged and complicated process.

There may not, however, be an equivalent awareness of the complexities of technology transfer in the electronics sector. The Chinese are eager to accelerate the introduction of advanced production technologies from abroad, but many foreign firms express considerable skepticism about China's absorptive capabilities in these areas. These companies take note of the shortages of high-quality raw materials, the absence of predictable power supply (an especially critical problem for semiconductor manufacture), and major deficiencies in the skilled manpower base in the factories as continuing constraints on the absorption process. In addition, China must train tens of thousands of service and applications personnel so that imported computers can begin to achieve better utilization rates. None of these factors represents an insuperable obstacle, but together they will take years of effort to overcome.

Nevertheless, the Chinese believe that their limited experience with importing production lines from Japan, Western Europe, and the United States offers grounds for encouragement. The Chinese point to the Jiangnan Semiconductor Plant at Wuxi as one such success story. The plant is not a turnkey facility, but entailed negotiations with dozens of Japanese and American vendors for separate equipment purchases. After early delays in receiving and installing some of this equipment, the Wuxi plant is now operational and highly productive. Chinese planners hope to repeat this pattern in comparably equipped facilities elsewhere.

However, it remains to be seen how widely the Wuxi experience can be replicated. Throughout the electronics sector, the backwardness of much of the equipment and the lack of a highly trained work force skilled in the demands of high-volume precision manufacture will remain a serious constraint. Thus, efforts to establish national centers for microelectronics development—an especially vital component in China's strategy for electronics development—will depend critically on the willingness of more advanced R&D units to transfer some of their personnel to these new centers. The Chinese also hope that scientific personnel receiving advanced technical education abroad will play a major role in the innovation process. Without a major increment to the skilled manpower base, the prospects for near-term success will remain limited.

Even assuming successful absorption in a few showcase research and production centers, problems associated with the diffusion of innovation within the R&D system as a whole could persist, especially in industries where the pace of technical change is very rapid, such as electronics. The skills and experiences required for successful innovation cannot be transplanted overnight, nor can technology be supplied "out of a box." The process of technological innovation and adaptation is thus both protracted and complicated. To sustain and accelerate this process, the Chinese must make far more effective use of existing R&D capabilities, refurbish factories that have used dated technology for decades, acquire substantial technical and manpower assistance from abroad, and persuade R&D personnel throughout the Chinese industrial system that in the future the potential rewards of success will outweigh the risks of failure. These are daunting if not impossible tasks for which the efforts have only just begun, and for which indigenous capabilities alone cannot suffice.

On balance, there are substantial factors arguing both for and against the prospects for innovation. The training of thousands of scientists and engineers in the West and the reinvigoration of the Chinese educational system should begin to provide a much needed infusion of more innovative talent into the R&D system. However, the lack of an effective market mechanism to match such talent with specific needs and the potential for resistance to more innovative approaches to R&D management could continue to impede the process of technological advancement. Similarly, the trend toward increased autonomy on the part of industrial enterprises—including enhanced opportunities to define their own strategies for technological development in relation to other levels of the R&D system—augurs well for the innovation process. But the major deficiencies of much of China's existing production equipment, the severe limits on high-quality raw materials, and continuing shortages of skilled workers—that is, the pervasive problems of the infrastructure—provide compelling evidence of the magnitude of changes that have only begun to be rectified. How the Chinese R&D system will address these opportunities and constraints will remain a fascinating issue, with important implications for the future of the Chinese economic system and for China's technical and commercial ties with the industrialized world.

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