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Technology Institutions and Policies

Their Role in Developing Technological Capability in Industry

Melvin Goldman
Henry Ergas
with Eric Ralph and Greg Felker

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FOREWORD

Successful industrialization depends on technological development. Continuous improvements in technology enable firms, industries, and economies to enhance productivity and build competitiveness in new areas. Advances in the economic theory of innovation, together with accumulated experience of policy makers and practitioners, have shed light on the process of industrial technology development (ITD) and the potential role of supporting policies and institutions. Government's ability to drive accumulation of technological capabilities by firms and industries through "public goods" investments in basic scientific research is now seen as limited, and important efforts are being mounted to reform isolated and ineffective public research establishments. It is also recognized that industrial firms must invest in acquiring technological knowledge and mastery, drawing on stocks of technologies from abroad and from external sources in their own countries. Beyond individual efforts in technological learning, firms are supported in important ways by their environment including the policies and economic institutions that shape firms' incentives to invest in technological learning, and provide complementary assets—technical skill, information, technical and financial support—to make such investments more productive.

Translating these generalities into policy making in developing countries remains a challenge. What are effective technology polices? What sorts of technology supporting institutions (TIs) are appropriate, and what roles can they play? Although there have been company, industry, and country-level case-studies, there has been a lack of comparative analysis taking account of variation across industries with different core technologies, industrial structures, and public institutions. To begin to fill this gap, the Asia Technical Department designed and led a multi-country, multi-sector study titled "Institutional and Policy Priorities for Industrial Technology Development". The project assembled research teams in eight economies—China, India, Japan, Korea, Taiwan, Mexico, Canada and Hungary—to study how firms in six industrial sectors have expanded their technological know-how, obtained support from external institutions, markets, and policy-induced sources, and interacted with TIs. The study involved both historical research drawing on secondary sources and the administration of surveys (through interviews and by mail) of firms and TIs using the same questionnaires in each location. Its results provide a rich base of quantitative and qualitative information on the policy and institutional aspects of ITD.

Carl Dahlman
Director-World Development Report
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ABSTRACT

The importance of developing and dissemi nating technology for industrial develop ment and competitivenes is widely recognized. Companies have to build technological capabilities themselves but also need to source technology outside the firm from customers and suppliers to technology institutions (TIs). This study of six industries in eight economies examined the role in building industrial technological capability played by outside sources particularly technology institutions (TIs) such as research and standards organizations and by directed policies such as tax incentives. It concluded that TIs have made a profound difference on industrial technology development where there are sufficient imperatives such as a competitive environment or manufacturing for an overseas quality-driven market pushing firms to improve their technology. TIs were particularly valuable for economies and in sectors where their role is to diffuse technology to help catch up technologically.

TIs and financial incentives have proved less adequate in helping technologically less sophisticated and smaller firms. Most countries have neglected traditional small-scale industry (SSI) and many TIs are not appropriate for communicating with enterprises lacking technical capability. If properly targeted, however, as in Japan, TIs can meet the needs of SSI in traditional sectors where they dominate. Financial and other incentives favor large enterprises even more heavily.

The most successful TIs are those which know their clients, understand clients' needs, upgrade their knowledge regularly and maintain incentives related to their mission. They complement other sources of technology usually helping in the absorption, adaptation, improvement or development of technology only in part with the rest done by the firm, perhaps with imported knowledge or with ideas of customers or suppliers. TIs cannot substitute for a good business environment, a stable

Governments can stimulate the building of TIs, develop TIs and programs supporting SSI and ensure that diffusion of known technologies is emphasized. But they should not run TIs. Where TIs do not support industry, they should be restructured to do so, modifying leadership, financial systems, structures and incentives. Governments need also to ensure an adequate flow and stock of high level technical manpower to staff TIs as well as private firms. Financial incentives need to be targeted to market deficiencies, such as the use of TIs by SSIs and avoid substituting for what firms would have done in any case.

EXECUTIVE SUMMARY

What Is the Study about?

This paper summarizes the findings of a study that aimed to determine the key characteristics of technology support institutions (TIs) and technology policies which support more rapid growth of technological capability in industry. These characteristics were expected to vary depending on: the nature of the industry (or sector), including the industrial structure; how rapidly technology is changing and the degree to which it is science-based; the country endowment, including the quality of training and its educational and institutional culture; and the characteristics of firms and their capabilities, as embodied for example in technical manpower, facilities and management attitudes. TIs' characteristics that were expected to be important were how TIs are organized and operate, including their internal incentive structure, management background and modus operandi, and approach to services and income generation. The study attempted to determine the efficacy and relative importance of various technology policies, incentive measures, TIs and other sources of technological know-how.

This paper also examines how various firms in different sectors and countries improve their technology to increase productivity and product quality and develop new products and processes. It seeks to understand the roles of different participants in the innovation process, including firms' engineering and R&D departments, customers, suppliers, foreign licensors, and private and public technology institutions.

Six economies--Japan, The Republic of Korea, The Peoples' Republic of China, India, The United Mexican States and Taiwan (China)*--were the subject of full studies. In Hungary and Canada study was more limited in scope. Although each economy is at a different stage of development, all have sizable industries in each economy of the six sectors studied (three each for Hungary and Canada). The sectors were selected to include a range of characteristics related to science and technology intensity, industrial structure, economies of scale, young versus mature industries, and kinds of customers. Study teams in each economy used the same instruments to survey firms (about eighteen interviews in each sector plus a random mailed survey) and TIs (up to ten interviewed in each sector), and also analyzed the evolution of the sectors, particularly as regards technological and institutional development. These analyses were complemented by case studies of interactions between firms and TIs.

What Do Firms Seek?

The surveys confirm an intensive use of outside support for technological improvement, and the range of these sources is varied. Users consider them complementary to other external, as well as internal, sources rather than as substitutes. If a firm has its own technical resources, personnel or an R&D department, it is far more likely to use outside technological sources, particularly public and private institutions. Larger firms are more apt to use TIs than small firms. Over 80 percent of firms with an in-house lab and more than 350 employees use at least one public TI compared to 31 percent of firms with fewer than 50 employees that do not have an in-house R&D lab. (See figure 1.)

Customers, followed by suppliers, are the most used external sources of technology, but the intensity of use of publicly supported TIs is more surprising. When the various kinds of public TIs are lumped together, more firms have used at least one public TI than either a customer or supplier as a source of technology. There are major country differences, however; intensive use is made of TIs in China, Japan, India and Korea. In Canada, least use is made of TIs even after controlling for the

Hereafter, these economies will be referred to in a shortened form, e.g. The Peoples Republic of China will be referred to as China.

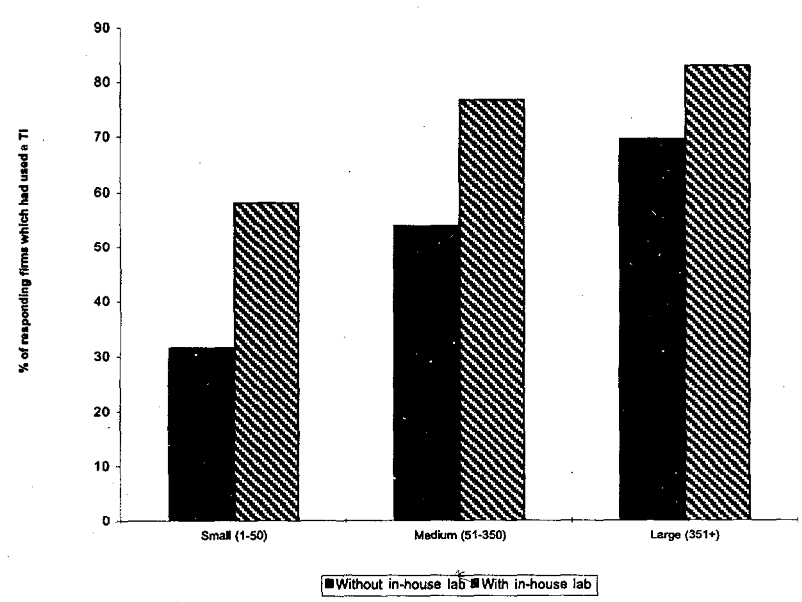
much smaller Canadian average firm size. In part, this variation reflects differing historical approaches toward learning and independence-what might be described as cultural differences, but it also relates to the supply of services. China and Japan have each built many technology centers, helping to explain high usage.

The overwhelming demand by industrial firms is for services related to what might be called diffusion, that is, the transfer and application of known technology. Firms most frequently use services related to information, standards and testing, problem solving (and trouble shooting) and technology training. And even when they use R&D services of TIs, they tend to want answers to particular questions, rather than the development of entirely new technologies. The study unearthed few examples where firms purchased off-the-shelf, self-contained technologies developed by TIs. This is in stark contrast to the claims and publicly projected image of many TIs, particularly R&D labs.

Not only do firms say they use diffusion services most, but those services are also the most frequently used according to TIs as well--this is true even when considering only TIs that carry out R&D. The "demand" for diffusion of known technology is not surprising. In so many industries technological know-how is so diverse and specialized that individual firms cannot possibly be current in all fields (unless they have a large technology support group of their own and are well structured to use it--which is all too rare). Most are aware of only a small fraction of the possibilities for innovation using the existing stock of technological know-how. The smallest firms in mature industries have little capability to identify their technical needs or questions, let alone search for answers.

Some needs can be satisfied through normal market channels or, as in Japan, through *keiretsu* --intricate private sector channels of cooperation--or through cooperative associations that may include independent firms across *keiretsu* lines. But even in Japan, where such private mechanisms are extensive, and where private research firms and consultants also have recently developed, government still supports many areas where the private sector does not. While less important and per-

Figure 1. Use of Public TIs by Firm-size and In-house lab / department



Note: TIs refer to national, regional, or local technology institutes; industry associations.
Source: Global survey results.

vasive in another advanced country, Canada, external support generally, and from TIs in particular, is important in technology improvement.

The study does not suggest an ideal model for cooperative inter-firm relationships, but it does emphasize the contribution such interaction can make to technology upgrading as well as ways that it might be encouraged. Business practices that spur cooperation between supplier and customer, and policies that encourage companies to learn from their domestic and overseas customers and suppliers (and more indirectly to export), clearly enhance a country's accumulation of technological capability. Firm interaction also can be fostered through TIs. A number of cooperatively formed TIs in Japan and one in India illustrate the potential for sharing technology as well as the delicate nature and importance of timing in any cooperative effort. Here too, government can be a catalyst. But these efforts work more effectively in certain sectors--textiles for one--that have many medium-scale firms and whose technological needs are not so advanced or closely tied to developing science. In science-based sectors like polymers, several publicly supported research labs in India have provided industry more effective support than have the industry-run cooperatives in Japan.

Characteristics of Effective TIs

Most of the elements that go into a well-performing TI are not especially different from those in a well-managed firm. An effective TI knows its market, understands its capabilities and limitations, matches the qualities and skills of its staff to the needs of the market, understands where the market is going and can adjust to it, and balances advertising its know-how and guarding its clients' confidence. A TI must identify and study its market and know its clients intimately, including their current desires and likely future needs. This implies that TIs need to interact with their clients, know their problems, and identify what they need. They must then determine what they need to learn and seek to achieve the right balance between responding to customer demand and investing in developing capabilities in anticipation of future needs.

Guidelines for management will depend on the domain of the TI--its market and the role it wants to play. The mix of activities to meet clients' current demand and investment in building capacity for their future need, for example, will vary by the type of service organization--standards and testing laboratory, training institution, R&D institute or multipurpose center; the nature of the sector and clients--whether its clientele is principally large-scale or small; and their degree of technological sophistication. The education and experience required of key technical staff depends on the clients and the services.

Staff quality must be technically excellent for the TI's tasks, with a level of expertise well ahead of its clients. But expertise is not enough. TI staff must interact with industry regularly to know their needs and how to communicate with firm staff. Furthermore, the TI should organize its incentives systems--particularly criteria for staff advancements (promotions, degree of autonomy, increasing responsibility and increased compensation)-to encourage individual staff to work for the goals of the organization, but also to ensure cooperation and teamwork.

Many other characteristics contribute to performance: systems for confidentiality, signals as well as incentives to staff, and varying approaches to bringing in new ideas and blood. Whether a TI is owned by government or the private sector (or whether the CEO is a world-renowned researcher or an industrialist) are not important determinants of performance. That is not to say that the CEO is unimportant or that government has no role; in fact, both are critical. Government normally must contribute to the institutional setup, and ensure that industry supports an infrastructure that helps raise the technological capability of many firms, not just a few leaders. Similarly, the leadership must set the tone of the TI, get the incentives right and emphasize the values of a service orientation and technical excellence. A technical and industrial background is likely to help a

CEO set the tone; TIs having a CEO with industry experience have on average nearly 20 percent more industrial revenue.

Incentives and Policies for Technology Development

Although the broader policy framework was not the study's principal focus, the survey results and the sector studies shed light on what constituted effective policies. First, where technology incentives--such as technology (or R&D) tax incentives, loans, subsidies, protection--are not specifically directed at small-scale firms, they have tended to be more concentrated and regressive by firm size than technical assistance by TIs. One-third as many firms as use a TI use any incentive. And these findings apply across different types of incentives and countries.

Historically, government interventions to guide or control technology acquisition and to license or limit production capacity have had mixed results. Japanese foreign exchange restrictions and controls on foreign technology acquisitions in the two-and-a-half decades after the Second World War, pushed firms to cooperate for licensing, diffusing and developing technology. In some sectors, notably casting, whose technology changed slowly and which had the skills to absorb technology, the effect was dramatic. In polymers, whose technology is more science-based and changes rapidly, Japanese government policies to constrain licenses, diffusion and capacity led to inefficiency and relatively slow technology development. Indian government policies across the industrial sector from the late 1960s to the 1980s similarly retarded many sectors. More positive, but still mixed results, occurred in Korea. But what distinguished Korea and Japan from India was the intense competition, both domestically and for export markets, among Japanese and Korean firms, while in India, until recently, exports took a back seat and competition was discouraged through capacity licensing and excessive protection. Many firms in all three countries, however, also benefited from the policy of induced learning, resulting from the need to be innovative and to reverse-engineer in order to compete. Where India appears to have succeeded is in building basic technological and industrial skills and with liberalization it is reaping the benefits. Government's earlier promotion of education and industrial development--the building and operation of small and large-scale factories in the private and public sector--provided the experience and developed the skills needed for today's rapidly growing and increasingly efficient industrial sector. All successful examples have had to pay a temporary price of inefficiency in order to learn.

Government's Role in Technology Development

As with its role in industrial development generally, government's role with respect to TIs is, first and foremost, to create an appropriate environment for technology acquisition and development, and to make available the right incentives. That means that a local industry (regardless of ownership) needs to operate in a competitive environment domestically and/or abroad to ensure concern for product quality and range and efficiency of production. In turn, that creates demand for TI services.

The appropriate environment includes an education system that produces high quality technical manpower and technology infrastructure with equipment and people that can support industry. Government's role is to promote both, but not to manage them. Where needed TIs do not exist, government might stimulate industry, an educational institution, or a private group to form them, or start them itself. Government can offer the right incentives and financial assistance to stimulate growth and service to industry.

Where an infrastructure exists but is not providing support, government is frequently part of the problem: in particular, the way it finances TIs and its frequently close control over TIs' activities. There are successful examples of institutional transformation highlighted in Chapter 5 (Boxes 7, 8 and 9). Common elements in successful turnarounds are "hard budget constraints", leadership as well as a clear vision of the institution's role and procedures, including incentives and programs for industry.

An important role for government relates to small-scale industry (SSI), which often receives almost no support. Only Japan maintains a network of TIs dedicated to SSIs, and these services are subsidized. It is a mistake to tack on support for SSIs to general TIs whose principal clienteles are larger more sophisticated firms. SSIs have different needs and lack the technical personnel to communicate with sophisticated technical staff of most TIs (hi-tech firms are different). TIs that focus on SSIs need to expose the companies to the benefits of change and generate a demand for technology improvement, as well as resolve problems brought to them.

Two approaches for supporting SSIs seem to be effective. The Japanese approach is decentralized and directed at geographic clusters of industries. TIs are supported by prefectural (county) government, and their primary purpose is to support local SSIs. TI staff work with their clients in many ways and most work relates to diffusion. The clustering of related industries in Japan permits regional institutional specialization in particular sectors. This approach has wider replicability since clustering is common in many places, although perhaps the model may need adaptation to function with a reduced Government role in countries where public institutions are weak.

A contrasting approach, which covers a smaller percentage of the SSI population, is the Taiwanese productivity center. The center is an SSI model of a TI that develops technological expertise in a generic area with wide applicability to a range of SSIs. The Taiwan center's expertise is industrial engineering and automation. Its services are well regarded, but they are used by only a few SSIs. This model is followed somewhat in Korea and is being adapted and spread in parts of China. The center's services are heavily subsidized and the TI is wholly Government-owned. This model too can be adapted for different environments by reducing the level of subsidy and the role of government in management.

Conclusion

Technology policy and institutions are important tools to help countries industrialize. But there are no simple solutions for targeting such policies, and some of the easiest to create, such as R&D and tax incentives, may be the least useful. Ultimately, there is no substitute for independently functioning TIs, which respond to industrial demand and look to their clients rather than Government for their normal operating expenses. TIs which perform well for the economy are technical and social demonstrations of good management practices. They know what their industrial clients demand and lead them to what they will need.

CHAPTER 1:
APPROACH OF THE STUDY

This report examines the use that firms in a group of developed and developing economies make of external sources of technical support in product and process innovation. It pays particular attention to the role in the innovation process of technology support institutions (TIs)--universities and technical colleges, private consultants and contract R&D providers, as well as public bodies such as central and local government laboratories, industrial extension services, and productivity centers.

The Nature and Importance of Technological Capability

The acquisition of technological capability is essential for industrial growth. "Technological capability" is not synonymous with the ability to develop entire technologies, the "breakthroughs" that play so visible a role in advanced economies. Rather, it is first and foremost the ability to learn, to master progressively the many elements involved in producing industrial goods. For almost all developing countries, this entails absorbing technologies that are in widespread use elsewhere. Absorption is neither easy nor passive. Considerable skill is required, for example to:

- identify the technologies that should be used, and design and build the facilities in which they are embodied;
- adapt facilities, processes and products to the peculiarities of local raw materials and other inputs, factor prices, and market demand;
- train personnel;
- ensure that plant and equipment are maintained and that quality standards are enforced;
- cope with breakdowns, unexpected outages, deficiencies in layout and scheduling, and unexplained changes in product or process performance; and
- adjust to process and product improvements when these occur.

The ability to master these skills is the central component of industrialization. The payoffs include the capacity to implement existing processes and to adjust to the changes in supply and demand that are the hallmark of dynamic, open economies. Yet the extent of this ability varies greatly among countries, with some--such as the fast growth economies of East Asia--rapidly upgrading their skills, while many others fail to implement even the simplest industrial processes. Those who can thrive grow faster under the impetus of "learning by doing," while the rest fall farther behind. Strengthening the ability to learn is consequently a central challenge for public policy.

Economists have traditionally viewed firms' innovation as depending mainly on their internal capabilities and efforts, a view reflected in the emphasis in conventional analyses on in-house R&D, and the relegation of external support to secondary status. The difficulties of contracting for technology have been viewed as limiting firms' reliance on outside for technical support, and external reliance has been seen as only a step toward full internalization of R&D. Policymakers and industrialists have long challenged this view and economists now have begun to do so. Three elements are important in this respect.

First, current analyses of the innovation process place great emphasis on spillovers--on the interdependence of firms' innovation efforts. These effects occur through a range of means, including observation by each firm of the innovation efforts of other firms, the publication of research, conferences and colloquia, the transfer of skills and knowledge between customers and suppliers, and the movement of staff among firms. Though it is conventional to view imitation as a relatively easy if not costless process, these spillovers do not occur automatically; rather, they require purposive action by the firms involved, most notably investment in the people and systems needed to learn. Firms' capacities to exploit these investments clearly affect their technological performance.

Second, the extent and pattern of these spillovers is increasingly viewed as depending not solely on the efforts of firms themselves but also on their institutional context. Recent analyses of "national systems" of science and technology (see para. 1.10) highlight the role of social institutions in determining the capacity to innovate. Some of these institutions, such as national research laboratories and standards-setting bodies, promote the development and diffusion of technology; others, such as educational institutions and the institutional infrastructure of capital, labor and product markets, may influence the ability and incentive to innovate, just as they shape other aspects of economic behavior.

Third, it is increasingly recognized that external sources of technological capability may be especially important in industrializing economies. Being further from the technological frontier, firms in these economies can most readily learn by observing the behavior of their more advanced competitors and adapting it. They can also draw on the expertise of suppliers and customers, who can help identify best practice. Finally, innovation requires the mobilization of a range of assets, many at least partially external to the firm (for example, people, sales and distribution networks, and suppliers). Producers in developing economies are most likely to be constrained by shortages of these complementary assets, and hence to depend for their long-term technological performance on public and private action to increase the availability of those assets.

These newer views of the innovation process, though seen in the academic literature, have not substantially affected public policy. This partly reflects the limits of the work carried out to date. The analytical framework is often poorly specified and incomplete; little empirical research has been done, and even less has been done to translate the perception that "institutions matter" into institutional design. It may also reflect the dominance of policy makers and advisors more concerned, out of fiscal necessity or ideology, with cutting back Government involvement.

Empirical studies of the characteristics of effective TIs and policies have followed one of three courses. A common approach is analyzing TI cases in one or more countries with or without an overall institutional framework (see Arnold, Bessant et al., 1993, and IDRC, 1993). Another approach is to analyze the experience of a group of TIs in one country. This is commonly carried out on behalf of policy makers eager to restructure or reduce government contributions to the technology infrastructure (notably commission reports in England and India such as Lord Bessborough, 1972, and Abid Hussain et al., 1986). The third approach is to examine technology policies and institutions as an element within the overall science and technology system of a country or countries (Nelson, 1992, and Dahlman, 1989, 1990). While many of these provided insights and hypotheses for this study, they do not have a common approach with an underlying framework to be tested across a range of countries. Few have dealt with the organizations and incentives of institutions, and none looked at sectoral differences. One study (Goldman, 1994), which examined four sectors in three European countries, served as a pilot for this study. (A range of works consulted for the study is in the bibliography. The list is not exclusive and some materials undoubtedly and unknowingly have been omitted.)

Focus of the Study

The study's aim was to determine key characteristics of TIs and technology policies that support growth of technological capability by industry. These characteristics were expected to depend on:

- the nature of the industry (or sector) including the industrial structure, how rapidly technology is changing and the extent to which it is science-based;

- country endowments, including the quality of training and education and its institutional culture; and

- the firm and its capability as embodied, for example, in its technical manpower and facilities and management attitudes.

TI characteristics that were expected to be important included TI's organization and operations, management background and mode of operations, and approach to services and income generation. The study attempted to determine the efficacy and importance of various technology policies and incentives, as well as types of TIs.

Approach: How the Study Was Carried Out

Most research on the innovation process has examined firms in industrial market economies, particularly the United States and the United Kingdom, but the questions here require a broader view. This paper therefore examines a sample of economies--India, China, Taiwan, Korea, Japan, Hungary, Mexico and Canada--spanning a range of levels of development. They also have had differing approaches to industrial development:

- *China* has been undergoing a rapid transition from a centrally planned economy to one in which market mechanisms are dominant.

- Although now in the process of liberalization, *India*'s economy has long been subject to extensive regulation and protection, condoning inefficiency and leaving large parts of industry inward-looking.

- *Korea* has had an outward-looking industrialization strategy for more than three decades. While encouraging firms to compete on export markets, the government for many years promoted a highly concentrated industrial structure, based on a small number of large, diversified conglomerates.

- *Hungary* was an early Eastern European industrializer, but from the Second World War until recently it was centrally planned. It was again the earliest of Eastern European countries to initiate market reforms, the effect of which was traumatic, since firms no longer had guaranteed markets in Eastern Europe and had to compete with sophisticated products from the West. Only certain industries survived the adjustment, including a few that have increased exports.

- *Mexico* long followed import substitution policies similar to those of many large developing countries. The 1982 crisis led to adjustment policies that have resulted in industrial readjustments. Its proximity to the US has a complex effect on institutional as well as industrial development.

- *Taiwan* has long had an outward approach to industrialization. Though large, often publicly owned firms have been significant in heavy industries, small to very small enterprises have accounted for most industrial output. Many are family-owned and many also generally highly export-oriented.

- In *Japan*, as in Korea, conglomerates are important, though they are generally looser networks of affiliated enterprises, and they draw on small and medium-sized secondary suppliers. Their flexibility has been central to the adjustment capability of an economy that is intensely competitive and trade-oriented.

- Finally, *Canada*, though it has had substantial tariff protection for many years and restricted foreign investment, is integrated into the North American market. Firms have achieved productivity levels that are very high by world standards.

An important caveat. All of these countries already have a substantial industrial sector that reflects different stages of industrial development. Historical analysis of sectoral and institutional development has been carried out in most of the countries, which along with statistical and case analysis helps explain their evolution as well as outcomes. This study does not, however, pretend to address the case of less advanced developing economies with only a nascent industrial sector.

This study makes use of common survey instruments in the countries and across the same sectors in each. Countries were selected to ensure a range of policy environments and industrial structures, as well as variation in achieving rapid technological and industry development. The existence of a sizable industrial sector was important to permit a big enough sample of firm interviews for statistical comparison.

Sectors were selected to ensure significant production and a range of firms in each country. The combination of sectors also includes industries built on different sorts of technologies--some mature, others emerging. They have variety in the following characteristics: science or technology based, structure, economies of scale, young and dynamic versus mature, and typical customer (the public, oligopsony).

The six sectors are: foundries, textiles, auto parts, machine tools, software and polymers. All six were studied in Japan, Korea, China, India, Mexico and Taiwan; only three sectors were studied in Canada and Hungary. In addition to these, pharmaceuticals, electronics, and textile machinery were studied in some economies to provide complementary insights. Pharmaceuticals were surveyed in India and Hungary, textile machinery in Japan, and electronics in Korea and Taiwan.

Country (economy) teams all followed the same approach and used identical pretested interview and mail questionnaires designed by Bank staff and refined with team leaders based on pilot testing. Each team conducted the following activities:

- A desk analysis, reviewing the evolution of technology, industry structure and technology policies and institutions overall and in each of the sectors. Interviews were conducted with industry associations, policymakers and academics, to provide background on industrial, trade and technology policy.

- Interviews of a sample of about eighteen firms in each sector representing a cross-section of the industry in terms of firm size, technological dynamism and location. The interviews aimed to understand how firms improve products and processes and the contribution of various actors and policies including (and particularly) TIs.

- Interviews with up to ten relevant TIs in each sector in each country to understand their services, structure (including incentives), staffing, funding, and perceived roles.

- A questionnaire survey mailed to randomly selected firms to check the interview results (on a non-purposive and larger sample) so as to expand the sample to permit analysis of a wider range of characteristics.

- Finally, case studies were done in most sectors of selected technology transactions between TIs and firms to understand the process of technological support and the relationships of participants in a technology support endeavor.

Analysis was carried out at the country level and on a cross-national basis. The country reports are supplemented by an analysis of the data combined from the various countries, which permitted hypotheses to be tested statistically, helping assure the validity of the results. For example, the quantity and importance of demand for varying kinds of technological services is examined, not merely for different kinds of firms of varying technological capability, but also in the same sector across countries at different stages of technological development.

We have approached the information from three perspectives. The country and sector reports, including historical studies, help identify trends and issues to be analyzed statistically. Second, statistical analyses test hypotheses about TI performance and firm demand. The 167 TI, and 704 firm interviews, and 2049 completed firm questionnaires were the basis for the analysis. Nearly all firm data cited in this report are from the mail survey. To give indications of the findings, results of regression analysis are presented throughout this paper. The reader should view these as indicative. Any particular numerical estimate should be understood as the midpoint of a likely range of outcomes. Unless otherwise indicated, such estimates are significant at the 95 percent confidence level. Similarly, when a characteristic is cited as an indication of effectiveness of a TI or a predictor of a firm's action, this is also significant at the 95 per cent confidence level[1] . Finally, case studies were used to deepen understanding and illustrate conclusions.

The results of the eight country studies are presented in Chapters 2 to 4. Chapter 2 provides an overview of the quantitative results, and Chapter 3 concentrates on what firms seek and also explains firms' use of internal and external sources of technology (including TIs) as well as of technology incentives and policies and discusses country and sectoral differences. Chapter 4 illustrates by case and analysis the characteristics of successful technology institutions and policies. An attempt is made to identify what constitutes good performance and to advise how to achieve it. Also discussed are the roles of various actors in building an effective institutional and policy environment for technology development. Chapter 5 attempts to present a vision of a successful technology policy and infrastructure for a middle-income developing country. It presents a summary of the role of government and on the need for and approach to a diffusion and small-scale industry orientation. It also offers cases and suggestions on how to transform TIs that use excessive government resources and have little effect on the economy. Examples of successful transformation illustrate the possibilities.

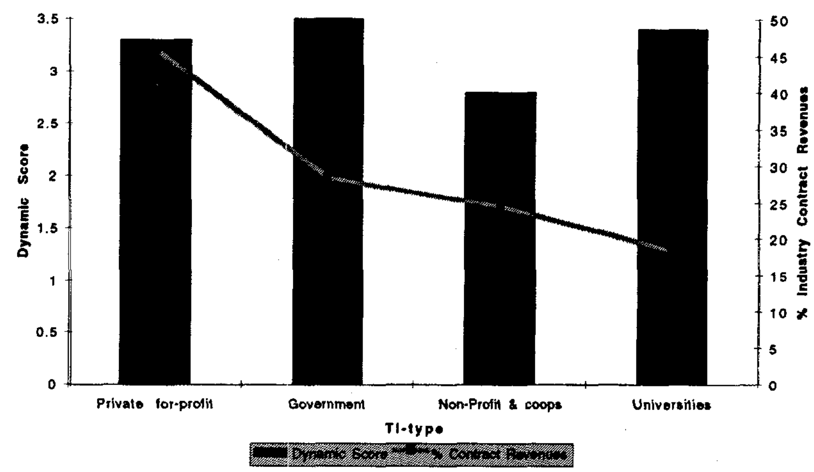
1 Cross-sectional analysis, which forms the basis of the statistical work of this study, is fraught with difficulties. First, the complex underlying structure of the relationships to be examined are generally unknown. While the models that formed the basis of the analysis were built on the best of available information, it would be serendipitous if they should coincide with the relationships examined. Second, even if accurate models could be developed, relations in cross-sectional data are extremely complex and involve many variables. While data availability generally limits the number of variables that may be considered, thereby leading to model mis-specification. For these reasons, the results produced in the paper have been subjected to a number of robustness tests, including comparisons among different models, as well as application of different statistical techniques to the same data and model. The following rules have, however, been generally followed. When the variable to be explained was qualitative, but scaled — e.g. degree of competition from 0 (none) to five (high) — ordered logits or probits have been used; when the explanatory variable involved discrete outcomes (ownership structure) multinomial regressions (logit and probit) were used; when the explanatory variable was censored, but otherwise quantitive, a maximum likelihood tobit estimator was used.

CHAPTER 2: SURVEY OVERVIEW AND RESULTS

TI Characteristics

The survey[1] of TIs covers interviews conducted of 167 institutions using identical questionnaires (Table 1).[2] Seventy-two percent of TIs were organized mostly along sectoral lines rather than by services, technical discipline, or interdisciplinary expertise. Ownership structure varies greatly, with public TIs predominant in China, followed by Korea and India. Japan has the largest share of private TIs. Japan and China have huge numbers of TIs, so that the sample there represents a small percentage of the relevant TI population, while in Korea and Mexico almost all relevant TIs were visited.

Figure 2 Reliance on Industry Contract Revenues and TI Dynamism by TI Type



Source: Global survey results.

The share of operating budget revenues derived from contracts with industry is an important measure of TI performance, and it varied significantly by country. Japanese TIs had the lowest reliance on contract revenues. However, the variance was high, suggesting that a strong subsidy element in technology services need not frustrate incentives for TIs to work with industry. China had the highest average reliance on contract revenues, in part because of decade-old measures to reduce untied budgetary support to TIs. Figure 2 groups TIs into ownership categories to compare their reliance on industrial contracts and the interviewers' composite esti-

Table 1 Sample TI Characteristics by Country

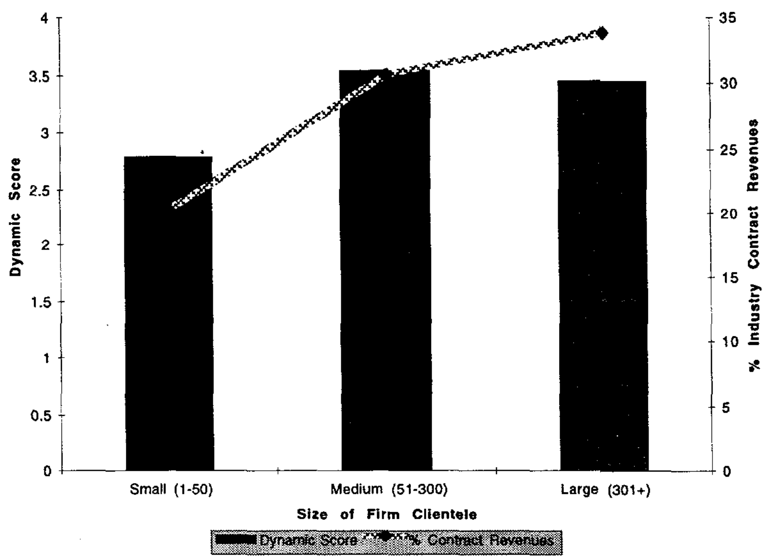
	China	Mexico	Korea	Japan	India
Number in sample	46	17	16	62	26
Mean year of founding	1972	1981	1979	1953	1965
Percent of sample TIs that are sector-specific	78	53	56	79	65
Mean staff	416	88	419	92	439
Mean percent technical staff	46	66	42	71	33
Mean percent of contract revenues (1992)	57	41	56	23	39

Source: Global survey result.

1 Unless otherwise stated, all tables, graphics, and data cited result from the analysis of the survey in the various economies and are cited as Global survey results.
2 Data for TIs is not presented for Canada, Hungary and Taiwan, because it is not available in a comparable form.

mate of the TI dynamism, scored on a scale of one to five. The dynamism score was based on the TIs' extent and ways of keeping abreast of and building capability in new technologies and incorporating environmental and industrial needs into their work. As expected, private for-profit TIs generate the highest percentage of revenues from industrial contracts and universities the lowest. This indicator, however, correlates poorly with the dynamic score, in which government- and university-linked TIs on average rank highest. There are variations from these averages including many dynamic private TIs, particularly in Japan, while many government or university TIs have high shares of earnings from clients. The TI characteristics that lead to successful performance are treated in Chapter 4. These results do suggest that the ownership of the TI is far less important to performance than might be assumed. Further, the need to generate revenue can encourage TIs to be industry-oriented, but is not necessary for promoting an industry orientation.

Figure 3 Reliance on Industry Contract Revenues and TI Dynamism by Client Size



Source: Global survey results.

Figure 3 shows the results found when TIs are grouped by size of client firm (number of employees). About 20 percent of TIs reported small firms as their primary clients, and a similar number served medium-sized firms, in contrast to the 60 percent of surveyed TIs whose primary clients were large firms. This result corresponds to a basic finding of the surveys of firms, namely that large firms tend to use TIs more extensively than do small and medium-sized ones. As expected, the share of contract revenues in the budgets of TIs serving large firms was twice that of TIs serving small firms. TIs serving medium-sized firms, however, were judged most dynamic.

Table 2 Firm Mailed Survey: Sample Size by Sector and Country

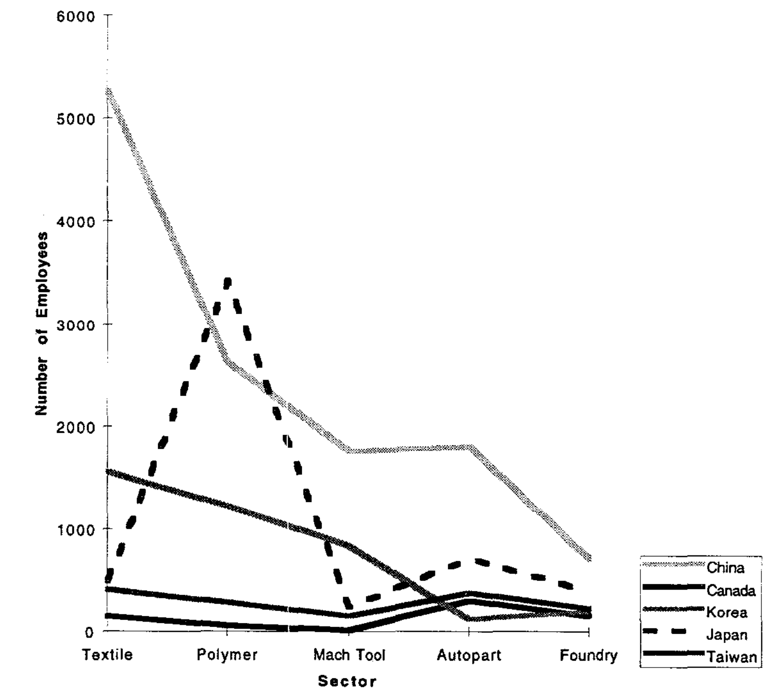
Sector	China	Canada	Korea	Japan	India	Taiwan (China)	Total
Polymers	35	39	29	25	6	22	156
Machine tools	36	19	35	44	10	26	170
Auto parts	35	16	34	64	35	94	278
Textiles	35	20	33	35	25	62	210
Foundry	36	13	35	51	8	98	241
Textile machinery	0	2	58	27	0	8	95
Software	35	4	0	42	27	117	225
Pharmaceutical	0	19	0	1	21	16	57
Electronics	0	52	42	2	0	187	282
Other	0	214	0	31	0	89	335
Total	**212**	**398**	**266**	**322**	**132**	**719**	**2049**

Source: Global survey results.

Firm Characteristics

In the mailed survey of 2,049 firms (Table 2, below), Taiwan had the largest sample size followed by Canada, and India had the smallest. In five of the six sectors (polymer, machine tool, auto parts, textiles and foundry), questionnaire responses were fairly evenly distributed across countries. The average age of firms reflects the timing of each country's industrialization, as well as the pace of firm entry and exit. Japan's firms are on average the oldest, followed by China, Canada, and India. The youngest samples of firms were in Korea and Taiwan. Textile firms have the oldest mean age among individual sectors, while software and electronics firms are the youngest. A basic indicator of industrial structure is provided by average firm-size as measured by number of employees. China's firms are the largest by far, registering the importance of large state-owned enterprises in the country's industrial structure as well as in the sample's coverage, and perhaps China's low ratio of labor to other costs and over staffing compared to other countries in this sample. Taiwan's small average firm size reflects the predominance of small and medium-scale firms in its industrial structure. Japan and India have a mix reflecting their industrial structure. Figure 4 and its corresponding table present a picture of the average size firm by country and sector.

Figure 4 Mean Number of Employees



	China	Canada	Korea	Japan	Taiwan (China)
Textile	5267	152	1563	502	428
Polymer	2636	65	1237	3437	292
Machine tool	1773	23	838	249	163
Auto parts	1817	307	131	721	385
Foundry	712	164	201	406	240

Source: Global survey results.

R&D intensity (R&D expenditures as a percentage of sales) is a measure of firm investment in technological innovation. Canada's sample had the highest average R&D intensity (8.1 percent). Korea and Taiwan also were above 5 percent. These high rates reflect the technology-intensive nature of sectoral coverage, and perhaps selection effects--more firms conducting R&D may have chosen to respond to the questionnaire. Japan's firms have the lowest average R&D intensity of the countries surveyed, although this partly reflects the large sample and high response rate in low R&D-intensity sectors like foundries and auto parts. As expected, software was the most R&D-intensive sector, and polymers also reported relatively high R&D ratios. Technologically mature sectors such as foundries and textiles have low R&D intensity, as do auto parts, where firms rely more heavily on technology from principal buyers.

Firms' External Technology Sourcing

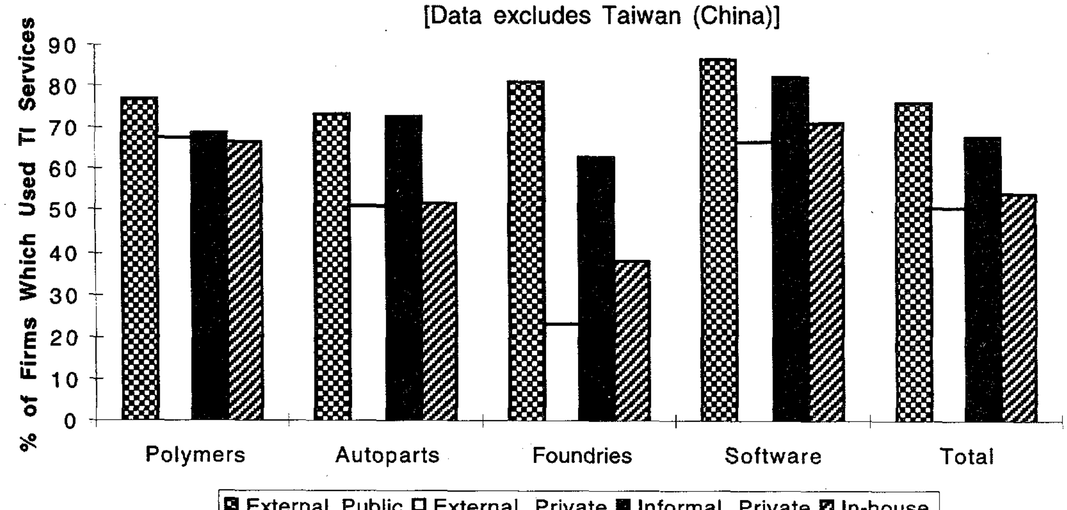
Firms' use of TIs and technology services highlights several important issues. Firms were asked about their interaction with a comprehensive range of technology sources, including public and private TIs as well as formal and informal sources of technology support. An important issue is the degree to which firms rely on public or noncommercial institutions, in contrast to private contractual sources of technology support or links with their major customers and suppliers. This question was addressed by grouping the technology sources into four categories: (a) public TIs, including national institutes and industry or research associations; (b) private contractual sources, such as foreign licensers and for-profit contract laboratories; (c) technical assistance from long-term suppliers and customers; and (d) firms' internal R&D or technology departments.

Striking was the magnitude of firms' use of formal public or quasi-public technology institutes. More than 70 percent had used a public TI at least once, while customers and suppliers were cited by fewer firms, and in-house R&D units by only half of the sample. The result held true across all countries except Canada, with the highest percentage of firms using public TIs reported by China, India, and Japan. Similarly, public TIs were cited by more firms than any other source of technology in every sector except pharmaceuticals (where use of foreign investors/licensers made private contractual sources the most cited source). Use of technology sources varied considerably across sectors, reflecting perhaps the differences in size distribution of firms, as well as the level of sophistication and rate of change of their respective core technologies. Figure 5 illustrates TI use for four sectors--polymers, auto parts, foundries, and software as well as the total sample. Firms in the science-based polymers sector reported comparable and high use of various technology sources, while auto parts firms cited long-term customers or suppliers far more often than private TIs or in-house research units. In the technologically mature foundry sector, 80 percent of firms used a public TI, surprisingly the highest percentage of the three sectors.

When we separate public TIs into national TI, local and regional TIs, and universities, and also consider suppliers and customers separately, the order of use frequency changes. Among individual sources, (i.e., when not grouping categories of technological sources) long-term customers was the most often-cited source of technology support (53 percent of firms), closely followed by suppliers and in-house R&D departments. Foreign investors and licensers were among those used by the fewest number of firms, along with academic and research associations. National TIs, private contract labs, local TIs and consulting firms each were used by slightly more than a third of the firms. Important differences in national TI systems are apparent. For example, national

Figure 5 Firms' Use of Technology Source by Sector

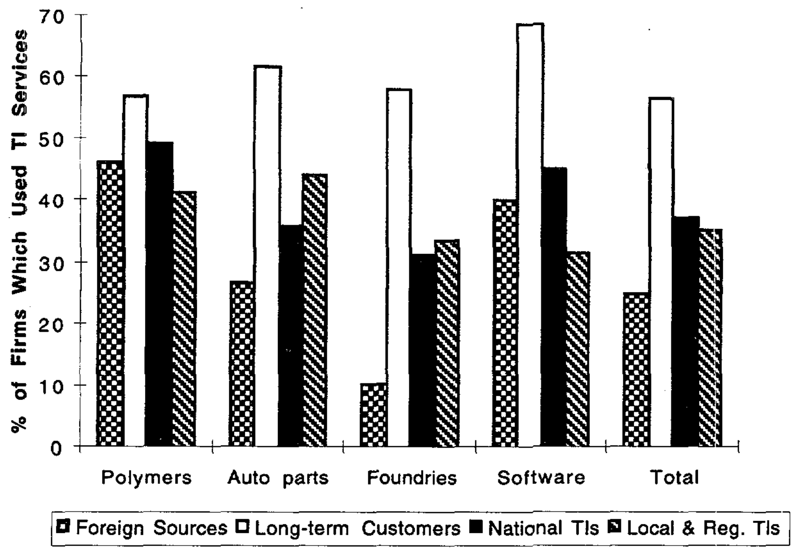
[Data excludes Taiwan (China)]



Source: Global survey results.

Figure 6 Firms Use of Technology Source by Sector

[Data excludes Taiwan (China)]



Source: Global survey results.

in the same rough order, but the difference between sources is relatively small.

One lesson that emerged from the study's interviews and historical comparisons is that while public TIs are important, diverse institutions are required to serve industries that vary in their structures and in the nature of their core technologies.

Figure 1 in the Executive Summary (p. 2) illustrates the frequency of use of public TIs by firm size. Larger firms tend to use TIs more extensively because of their greater internal resources. More significant than size is the presence of internal labs or technical departments: firms with internal resources were more likely to seek outside help, from public institutions in particular. Moreover, small firms with internal laboratories were twice as likely to use public TIs as those without internal laboratories. These results suggest the difficulty in reaching and serving small firms, particularly those without internal capabilities.

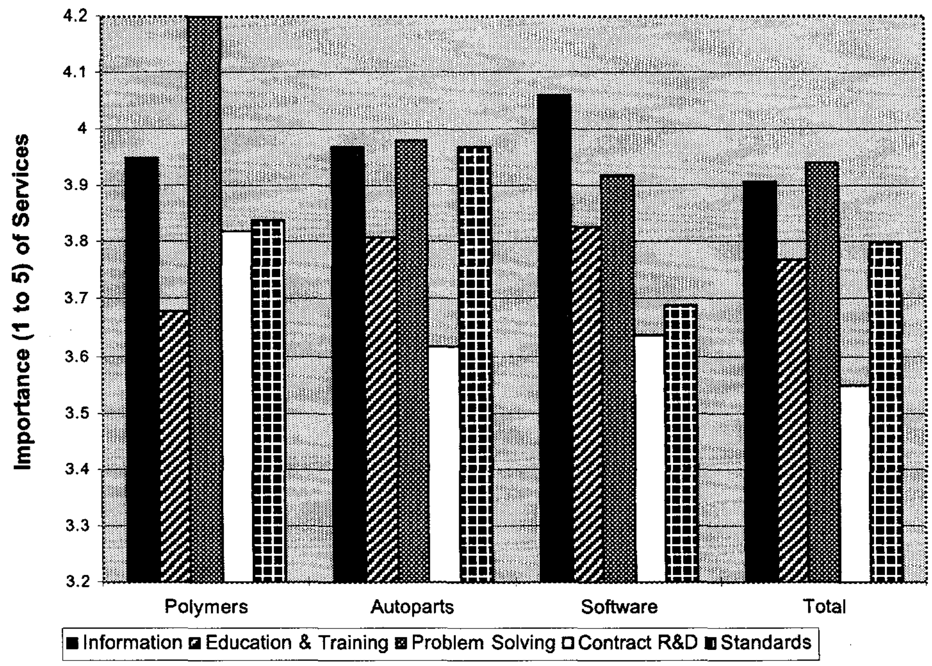
TIs and foreign investors are important to Korean firms, but less so in Japan, where local/regional TIs and industry associations play a greater role. Firms in India also use industry associations as well as private consulting firms.

The pattern of use of individual technology sources was roughly similar across sectors with long-term suppliers and customers again most heavily used. But there were differences by sector. In-house R&D labs were least important in mature sectors such as foundries and customer-driven sectors like auto parts, but they were more prominent in innovation-intensive sectors like polymers and software. Figure 6 compares the use of foreign investors and licensers, long-term customers, national TIs and regional/local TIs in four sectors (plus the total sample). While long-term customers were the most frequently cited in each, use of foreign investors and licensers ranged from almost half in polymers to only 10 percent in foundries. Polymer firms reported using national and local TIs for technology support almost as frequently as they use long-term customers, whereas relatively fewer software firms relied on public institutions. Of the firms who use different sources, the ratings of importance for technological improvement are

Firms' Demand for Technical Services

Firms used basic technological services - information, education and training, and standards and testing - more often than advanced services requiring more creativity, such as contract R&D or technical problem-solving. This result was true for all countries, though the difference was largest in India and Japan and smallest in China (where state-owned enterprises reported frequent use of R&D services from group laboratories). Similarly, all sectors reported more frequent use of basic services than advanced ones.

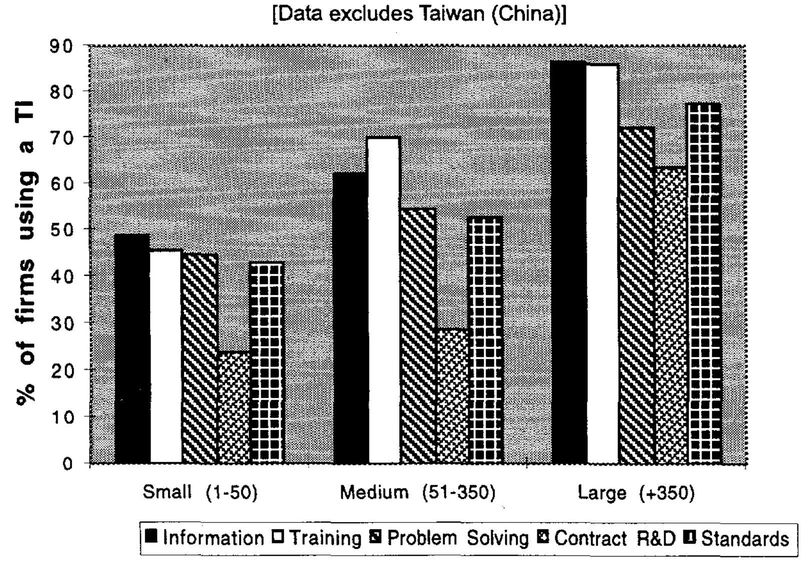
Figure 7 Importance of TI Services by Sector



Source: Global Survey Results.

The use of individual services varied across countries, sectors, and sizes of firm. The most-often cited service in Japan was education and training; in Korea it was information services; and in India it was standards and testing. Contract R&D was least cited in virtually all countries. Individual sectors differed in the importance attached to their use of technological services, as illustrated by Figure 7. While most sectors reported information and standards/testing as most frequently used, problem solving and information were most important when firms rated services for their effect on technological improvement. Polymer firms attached greater importance to problem-solving and trouble shooting than to other services and also attached greater importance and used contract R&D services more than firms in other sectors. This reflects the sector's science basis and rapidly changing technology. The pattern of service-use was roughly similar across firm size. However, as Figure 8 illustrates, the gap between use of basic services —information and standards/testing—and contract R&D was relatively smaller among large firms.

Figure 8. Use of TI Services by Firm-Size
[Data excludes Taiwan (China)]



Source: Global survey results.

In sum, basic services that diffuse known technology are the most critical element of TIs' support of firms' technological learning efforts. When firms look for external technology support, it is most often in the form of information services, standards/testing, and education and training. Larger firms and firms in science-based or high-technology sectors make greater use of contract R&D and technical problem-solving but continue to source basic services even more frequently. However, firms that use more complex services like problem-solving tend to value them more highly.

CHAPTER 3: FIRMS' PATTERNS OF USE

Introduction

This chapter summarizes the results of the firm surveys and draws implications for policy recommendations. One major conclusion is that, to be effective, TIs and governments must develop a market-by-market focus to provide a wide range of firms with technological help. For external support to be of help, it must be matched to the diverse needs of firms. A second major conclusion is characterized by the adage: to those who have, more is given. A weakness in government, university, and industry technology support efforts is that they tend to end up developing technology with larger firms and those that have in-house expertise, even if their objectives are broader. This is both inefficient--program benefits could be increased by shifting some expenditures to services and industries that receive little attention, such as diffusion of available technology in traditional sectors like textiles and foundries --and inequitable, as most resources are claimed by a narrow set of firms.

Analysis of survey results also suggests that innovative firms look beyond domestic markets. For example, R&D expenditures tend to be higher among firms with a greater share of exports. Firms that are aware of a technological gap with the rest of the world are more likely to be engaged in R&D, and are more likely to seek external advice. India is the exception that might prove the rule. Its firms' poorer R&D performance in the survey might be explained by their traditional insulation from international competition, and the failure of export oriented Indian firms to seek domestic external information sources might stem from skepticism as to the value of TIs "insulated" from the world industrial and technology market.

Section B offers a model of how firms learn. In particular, it argues that learning depends on a firm's in-house capabilities, which must be exploited to access external sources of technological information. Without internal technological strength a firm's ability to utilize outside sources is severely handicapped. This model is strongly supported by the survey data, detailed in the chapter's remaining sections. Section C begins within the firm, looking at what drives R&D. It finds R&D expenditures to be most strongly associated with large technologically advanced enterprises with high levels of training and an export orientation. It also seems that firms which see themselves as more technologically advanced at home than abroad are more likely to engage in R&D. These predictors of R&D expenditure turn out to be also strongly related to a firm's use of external technological sources.

Section D begins the analysis of external sources by highlighting the largely complementary relationship between use of in-house and outside sources. That is, a firm's internal resources are critical to its ability to access external sources. This relationship is strongest for medium-sized firms, because to some extent larger firms appear to substitute internal sources for external. The Chapter continues examining the pattern of external use, starting with those sources with regular nontechnical contact with the firm (customers and suppliers) and then moving to more specialized and distant sources (foreign licensers, private consultants, contract R&D facilities, and government TIs). Use again is found to be positively related to the firm's size, its internal capabilities, export orientation, and the difference between the firm's technological rank in domestic and world markets. Broader government programs--grants, tax concessions, technology loans, tariffs, etc.--are considered in Section F. The chief beneficiaries of these are large companies, especially those owned by the government. The chapter concludes with policy implications in Section G.

Firms and Learning

Firms learn from each other. Not only is conscious imitation widespread, but often technical staff of competing firms assist one another. Firms also "buy" technical information and skill bundled with other goods and services-be it through inputs (relations with suppliers) or outputs (relations with customers). And firms purchase technical knowledge as such, through contracts with consultants, public research institutions, and training centers, and they participate in cooperative projects involving technical advance, ranging from the setting of standards to collaborative research. Evidence of "learning from each other" was found in all countries, sectors, and types of firms surveyed.

These external sources for innovation may be even more important in developing economies, where firms mostly seek older technology. As a result, complex transactional problems involved in out-sourcing R&D do not arise and external sources, such as suppliers of capital goods or purchasers of final output, may already be active in the market. At the same time, the firms' internal technical skills are likely to be weaker, and their ability to increase skills more constrained by shortages of capital and of skilled staff than firms in the industrialized world. External sources may then allow some reaping of economies of scale and scope--which can be considerable in areas such as instrumentation, technical documentation and training--as well as easing bottlenecks of financial resources and trained personnel.

These considerations suggest an interdependence of internal and external sources (as Box 1 illustrates) in the innovation process. External sources may provide stimulus and support, but at least some internal technical resources are needed to assimilate skills and capabilities from outside. A three-stage approach may assess the extent and nature of this interdependence:

Box 1

Korean Auto Parts Company Develops Technological Capability

Korea's largest auto parts company, Mando Machinery Corportation, manufactures motors, electrical and electronic parts, air-conditioning, brakes, and machine tools. It employs 6,500 including 410 technical personnel, and since the mid-1980s has built a large research organization. Formed in 1962, Mando developed much of its technological capability through licensing and reverse engineering. As technology became more sophisticated and foreign companies became reluctant to license, the company built up its technological capability, concentrating on sophisticated value-added products and materials and engineering applications in nine specialized centers .

The company uses external sources, particularly TIs, extensively including the well regarded Korea University where it holds two-day workshops four times a year to increase communication and technical knowledge among its technical staff. It has worked with many universities and the Korea Institute for Science and Technology (KIST) to develop components and has participated in multi-company, government- coordinated R&D projects.

In 1988, realizing that foreign companies would not readily license recently developed sophisticated technology related to electronically controlled suspension (ECS), the company decided to build an ECS system itself. The technology is difficult to master without capability in many technical areas, including vehicle dynamics, sensor technology, electronics and mechanical engineering. Instead of developing all capabilities in-house, it obtained support from KIST. With commitment and push from the principal customer, Hyundai (which initially was skeptical about Mando's capability to develop the technology), by 1994 the company's ECS was being installed in Hyundai automobiles. In 1995, Mando produced 30,000 units.

Source: Based on the survey work of Se Joon Yoon and Snag Pyo Kim of Yonsei University, Korea.

identifying first the characteristics that appear to shape firms' internal technological capabilities; then assessing the influence of these capabilities on the use of external sources of technological support; and finally examining the determinants of the sources and services that require some external support.

Internal Capabilities: The Firm's Involvement in R&D

The ratio of R&D expenditure to sales[3] varies among countries and sectors. As is typical of cross-sectional analyses, much of the variation does not appear to be systematically related to the variables covered by the survey. However, where there is a pattern, three sets of factors seem important in explaining R&D expenditures: context, market position, and corporate strategy.

Context. While the firm's size does not seem to influence its R&D intensity, the sector in which it operates does. In technologically mature industries offering fewer opportunities for technical advance, such as foundries, automobile parts and textiles, firms tend to invest less in R&D than their other characteristics would suggest. Country factors are also relevant. Firms in India appear to "under-invest" in R&D, while those in Korea invest more heavily than predicted by other characteristics.

Market position. The closer firms consider themselves to be to the frontier of best practice, the greater the R&D expenditure.

R&D is also higher among firms that rate themselves as technologically more advanced when compared to domestic rivals than they do when compared with rivals in foreign markets. Such a firm might be better positioned and motivated than its domestic competition to take on international best practice.

The ratio of exports to sales is also positively related to R&D intensity. Participation in world markets not only provides competitive discipline, but also enhances opportunities to learn and secure returns from innovations.

Low investment rates in R&D are observed in firms facing especially intense competition in their home market, possibly reflecting a reduced ability to appropriate gains from innovation.

Corporate strategy. Especially important are the firm's policies for human resource development. Training and R&D intensities appear to be strongly complementary. This is presumably because exploiting the results of R&D requires skilled people.

Given these results, what might explain the apparent over-investment in R&D in Korea and the corresponding under-investment in India? Two other relationships emerge from the analysis. First, the Indian firms seem to have faced less domestic competition than their counterparts, particularly in Japan and Korea, and domestic market-share leadership seems to have sheltered Indian firms from competition more than is the case in the other countries.[4] Japanese firms, almost regardless of their market share, rank themselves as highly exposed to competition. In Korea firms with high domestic market shares report greater competition than do small firms. But for Indian firms the reported intensity of competition falls as domestic market share rises.

Second, in India lower domestic competition seems to correspond to a weaker orientation to exporting. While Indian firms appear to have significantly lower export propensities overall, export shares seem especially low among firms with a high share of the domestic market (though this effect weakens at the top end of the market share distribution). In contrast, newer firms in India seem to have higher export propensities than would be expected on the basis of their other characteristics.

3 Broadly similar results were obtained using other indicators for internal technological capabilities, such as the share of technical staff and whether or not a firm has an internal R&D department.

4 Surveys were carried out in 1993 and 1994. The competitive environment in India has changed significantly since then.

Together, these findings suggest that the Indian under-investment in R&D may reflect the degree to which dominant firms have survived without facing the challenges of either domestic competition or export markets. The contrast between Korea and India is especially striking in this respect: Korea's high market-share firms, which are relatively active exporters, invest especially heavily in R&D, while a similarly placed Indian firm underinvests in R&D. This reinforces the suggestion that an exposure to international competition can affect a firm's R&D expenditure.

Looking Outside the Firm: The Relationship Between Internal and External Technological Resources

The survey results indicate that firms view their internal technical departments as relatively low-cost, easy to access, and good at maintaining confidentiality. Still they make substantial use of external sources in developing products and processes. Overall, 82 per cent of the firms drew on at least one external source for these purposes. Analysis shows that the extent to which firms use these sources depends on their internal capabilities, corporate strategy and structural characteristics. The main relationships are summarized below.

Firms that have used an in-house department to develop products or processes are far more likely to have also used external technological sources than those that did not use an in-house department. Presumably this reflects these firms' greater absorptive capacity. A further "push" to outside sources comes from the perception that their internal facilities are inadequate both in terms of infrastructure and of practical problem-solving ability.

- ✧ Larger firms use external sources more frequently holding all other characteristics constant.

- ✧ Despite the implication of strong complementarity between internal capabilities and the use of external sources, large firms with very high ratios of training outlays to sales (and which are consequently most likely to be able to draw on in-house skills and resources) are less likely to draw on external technological institutions.

- ✧ This last relationship, however, does not hold for medium sized firms. Those medium sized firms with high training outlays are especially likely to use external technological support. In other words, for larger firms internal skills can substitute for external sources, but among medium firms reliance on external support complements internal skill development.

While these patterns hold across the full sample of countries, there are also striking differences. Three deserve note.

In India, the firms most likely to use external help in product and process innovation have high shares of the domestic market. External sources seem less attractive than they are elsewhere to smaller and medium-sized firms; indeed, medium-sized, export-oriented firms are less likely to use these sources in India than in the other countries. This may reflect skepticism by firms of "insulated" TIs having the capability of supporting export-quality technology. It may also reflect Indian TIs' inadequate attention to marketing their service to other than the largest companies.

In Korea, the larger, more successful firms tend to internalize their technological capabilities. In particular, those with high world market shares make less use of external help in developing new products and processes than their size and other characteristics might indicate. The Korean firms most likely to make some use of external sources are significant exporters and view themselves as technology leaders domestically but not internationally. For these firms, which are frequently mid-sized and which tend to rate themselves as facing intense competition, external sources would seem to provide a means of bolstering a vulnerable market position.

In Japan, on the other hand, the use of external sources tends to be more evenly spread across firms, including those lacking in-house development departments. In contrast to the Korean model, firms with high shares of world markets tend to make greater use of external technology sources. At the same time, external sources are also important to firms with mostly domestic sales--for example firms in the metal castings and machine tool industries, which sell to larger firms within the same *keiretsu*. Many of the firms in these industries lack an in-house development department; external sources seem to play a greater role as replacements for such departments in Japan than they do elsewhere. This may be because the range of Japanese TIs--national, regional, and local--better satisfies the needs of firms of different sizes, sectors, and capabilities. Similar decentralization and specialization by size and type of TI may be valuable elsewhere.

Patterns of External Use: Customers and Suppliers

Among external sources of technical assistance, long-term customers and suppliers are the most commonly used.

Firm responses highlight some of the problems that reliance on vertical links for help in product and process development entails, notably the lack of confidentiality, the difficulties of securing "ownership" of innovations, and the intermittent nature of assistance. But long-term customers, in particular, are seen as readily available ("fast and easy") providers of assistance, capable of solving problems, useful in developing products and improving processes, and an important means of securing contacts. (Benefits and problems of various external technological sources are summarized in Box 2.)

The perception of vertical links is widely held, but the actual use of these links varies between countries and across the industrial structure. Given the importance of long-term customers, the analysis focuses on the factors that shape their role.

Firms with an in-house development department are most likely to have received help from long-term customers in product or process innovation. Despite this complementarity of in-house resources and vertical support, the largest firms (those in the top decile of firms ranked by firm size) make less use of customer relationships. Firms that rank their technological capabilities more highly compared to domestic firms than when compared to foreign rivals (a difference referred to here as the firm's technology gap) make greater use of these relationships. Customer relations, in other words, seem important to firms that are "catching up" internationally, especially in Japan, India, Taiwan, and among medium-sized, export-oriented firms in Korea.

Analysis of the services that customers and suppliers provide to innovating firms also highlights the differing roles of vertical links. Overall, medium-sized firms do not make especially heavy use of vertical relations, but they do rely on customers and suppliers for information about technological and market developments. In contrast, the smallest firms use customers and suppliers for problem-solving, commercial advice and building contacts.

Foreign Licensers

While reliance on customers and suppliers is widespread, the use of foreign licensers for technical support is concentrated. Some 17 percent of firms in the sample have drawn on foreign licenses or partners. Foreign licensers are regarded as the best source of ideas about new products and processes, and as having the strongest capacity to solve problems. But they are costly to deal with because of high fees, distance and sheer technical complexity.

Few firms have the resources to overcome these obstacles. The primary users of foreign licenses are larger firms (though the size effect is reversed at the top end of the size-class distribution) that operate in oligopolistic home markets, have in-house technical capabilities, export, do so as "technology followers," and are tied into vertical links (including with foreign firms).

The extent of reliance on foreign sources also depends on the sector characteristics. In the technologically complex polymer industry, where products and processes are demanding and amenable to codification, firms are twice as likely to acquire foreign licenses. Firms in the relatively mature foundry sector, where "tacit" know-how tends to be more important, are less than half as likely than other firms to have foreign licenses.

Finally, firms in Canada--which has high productivity by world standards and is open to foreign investment (which may be a substitute for contractual licenses)--are least likely to rely on foreign licensers. Firms in India, whose Government restricted foreign licenses for many years as part of its inward orientation, also make less use of foreign licenses, despite low productivity levels.

Consultants and Private Contract Facilities

Consultants and private contract R&D also play a limited role among firms, although the extent differs among countries--Canadian firms rely more heavily on these sources, Japanese firms rely less. Firms recognize that they are a good source of entirely new ideas and are generally technically competent and reasonably timely, but they are expensive. In addition to high fees, they seem to involve sizable transactions costs, because of the difficulties in specifying the problem, selecting among consultants, and assessing their value. As much as the out-of-pocket costs, it may be these transactional difficulties which lead many firms to dismiss private consultants.

Reliance on private contractors is therefore limited by the firm's capacity to manage the relationship and to learn from it as well as the cost. Survey results highlight these constraints. Large firms, and firms with an in-house technical department, are about three times more likely than others to use private contractual sources of technical support: the smallest firms are about half as likely to use consultants as the firm population overall.

Technology Institutions

In contrast to the private sources, public TIs--national, regional and local technical laboratories, standards institutions and universities and technical colleges--are widely used in all the countries except Canada, where private sources predominate. Public sector dominance is, naturally, pronounced in China, but even in Japan, Korea and India firms draw primarily on public sector institutional[5] support.

There are substantial differences in how and by what sorts of firms public TIs are used. Even correcting for the effects of in-house capability, the largest firms are the primary users of national technical laboratories, universities and technical colleges, and research and academic associations. The gap in use by larger firms and others is much smaller for local and regional technology centers and industry associations. The contrast between the use of national institutions on the one hand, and local and regional institutes on the other, is seen in several patterns:

- National TIs are most used in Korea and least used in Canada. Taking country differences into account, the typical clients of national TIs are dominant firms, some of which are government-owned or subsidized.
- Mid-sized firms, most notably those without an in-house development department, make less use of national TIs, which are frequently viewed as too slow and bureaucratic. National TIs in fact were the most frequently cited for "red tape".
- The gap between large and small firms is considerably reduced for frequency of use of local and regional TIs. They are viewed as having less techno-

5 "Institutional" in contrast to the more informal support provided by customers, suppliers and foreign licensers.

logical capability than national institutes, but are considered easier to use. They are also least frequently cited as incurring problems of confidentiality.

- ✧ Medium-sized firms are substantial users of local and regional bodies. Use is especially high among firms without an in-house technical department, whose functions the TI would seem at least partly to replace.

- ✧ Strikingly, the smaller firms in Japan are nearly five times more likely than the average firm to use local and regional technical institutions. This may reflect their extensive availability in Japan and their responsiveness to industrial needs (see Chapter 4 below).

These differences partly reflect the different purposes of respective TIs:

- ✧ The development of entirely new products can require complex skills, which users perceive many of the smaller bodies (such as regional and local TIs and industry associations) to lack. National laboratories and universities and technical colleges have the skills but are difficult to work with, especially for firms that lack in-house capabilities. It is consequently the larger firms which tend to draw on the latter bodies, frequently for the development of new products or as a source of substantially new ("stimulating") ideas.

Regional and local TIs are seen as unable to develop new products or generate ideas. But they are the least distant source, and are viewed as good at solving product or process improvement problems — both by providing expertise and by allowing third-party use of facilities. Medium-sized firms especially use intensively these TIs for applied problem-solving, as well as for technical information, help with standards and education and training services. Industry associations are seen as poor at problem-solving but important for securing contacts, building networks and providing exposure to new ideas.

Overall, this diversity of patterns of use ensures that contacts with TIs are relatively pervasive throughout the industrial structure — although it is only in Japan that even the smallest firms seem able to draw on public sources of support for developing new products and processes. There is an important contrast here with the distributive consequences of other instruments of technology policy.

Government Policies: Services versus Financial Assistance

The largest firms were nearly three times more likely than average to have received government grants, tax concessions or special technology loans (government-owned firms in turn were twice as likely as private firms to benefit from these instruments). The disparities in access to government procurement and protection from competition were somewhat smaller. Only those forms of assistance most frequently provided through TIs and aimed at promoting technology diffusion — help in developing standards and subsidies for education and training — were used by small as well as by larger firms.

Policy Implications

External sources of technical support play an important role in all the countries and industries. They tend to complement rather than replace internal firm capabilities, though they can help small or medium-sized firms compensate for gaps in skills and facilities. Whether the full potential of external sources is realized depends on supply- and demand-side factors — that is, on whether firms are encouraged by their environment to develop internal technical resources and to improve products and processes, and whether support institutions for innovation are well designed and managed.

Economic and social policies that encourage firms to enter world markets provide in themselves incentives for technological development. Even exposed to these incentives, though, firms are unlikely to have all the skills they need. The private, largely contractual, TIs are really accessible only to the largest, most sophisticated firms; smaller- and medium-sized firms face substantial obstacles. Government support such as loans, grants and tax concessions, as well as procurement and protection from imports, are also of greatest use to the largest firms. The survey results show that public TIs can reach at least some of the other firms, but often they are ineffective. Designing TIs that can meet these needs is a central challenge.

The biggest handicap of smaller firms is their lack of technological expertise, which limits their ability to use external suppliers of technological information. They need reliable information brokers as much as information providers. Small, less technologically advanced firms neither are able to judge whether a provider can meet their needs, nor can they use the expertise offered, lacking the skills to assimilate this information. The effectiveness of government programs can be greatly enhanced by a recognition of this.

Distinguishing between large and other firms is not enough. Firms' diverse needs are broad. This is illustrated by the survey on R&D. R&D is most likely to

Box 2

Benefits and Problems of Technological Sources

Firms were asked to cite the benefits and problems of each external technology source used. Interestingly,the patterns apply across countries and are useful in drawing the conclusions of the study. The raw data indicated that (as expected) benefits and problems were most frequently associated with the most used sources: customers and suppliers. However, weighted by usage, foreign sources, research associations (RAs) and in-house labs were cited as frequently as customers and suppliers for benefits, and foreign sources, private labs and consultants, national TIs and RAs had the highest percentage citation of problems.

Speed and ease of use and the ability to solve problems were the most frequently cited benefits (each 20 percent) from external technological sources. Only private contract labs offered faster and easier service than average. While universities and technical schools, private consultants, and local and regional TIs were all good at problem solving. Other benefits cited were product development, building contacts, idea stimulation, and quality improvement (each with about 10 percent). As expected industry associations were associated with building contacts, as were academic associations. The latter excelled at idea stimulation, as did universities, technical colleges, and consulting firms; local and regional TIs and research associations stood out for their shared facilities, and firm laboratories had low cost. (However, shared facilities and low cost were the least cited benefits.) Long-term customers and suppliers, foreign sources, and national TIs were not strongly noted for any particular benefit. Long-term suppliers were seen as somewhat cheaper than average (their costs are hidden); foreign sources were better at product development; and national TIs were noted for shared facilities.

The most commonly cited problems were high fees and the inability to solve problems (18 percent each). Lack of timeliness (16 percent) was next. Private contract labs and consultants stood out for excessive fees, also a complaint about foreign sources. Technical disability and lack of timeliness were relatively evenly spread among sources, though academic and industry-related sources tended to suffer most. Red tape characterized national TIs and to a lesser extent local and regional TIs, while private contract labs were cited least in that regard. Long-term customers and suppliers, and especially in-house facilities, tended to have problems with personnel continuity. Customers and suppliers failed to protect confidentiality, for which in-house labs and local and regional TIs received relatively fewest complaints. Inadequate rules for research ownership was a serious problem of research associations, and to a lesser extent of long-term customers.

Sources: Global survey results.

be carried out by larger firms with strong in-house technical capabilities in sectors with rapid changes in technology, such as polymers and pharmaceuticals. Such firms use national TIs and foreign sources, but see local and regional TIs as poor at generating ideas or developing products. Most small and medium-sized firms, on the other hand, are rarely interested in cutting-edge R&D, partly because they simply cannot assimilate it, or even formulate the questions that might bear profitable answers. As a result, they make less use of national TIs and characterize them as slow and cumbersome. But small firms are relatively interested in applied problem solving, and medium-sized firms desire information about technological and market developments. These services are accessible from local and regional TIs.

No doubt the benefits of government programs may be increased with more careful targeting of firms. The survey suggests that small and medium-sized firms (SMEs) fail to exploit government programs adequately. SMEs underutilize the high profile and well-funded national TIs. But that is even more true of broad industry policies, especially grants, tax breaks, and technology loans. In many instances, the greatest potential for development lies with smaller firms that lack the resources to build internal technological expertise or to lay claim to funds offered through government programs. The benefits from shifting a few dollars of expenditure away from generously supported firms' activities such as R&D in national TIs, toward firms that are relatively unsupported, are likely to be high. Careful analysis of the costs and benefits of programs is needed, particularly of projects and policies that could benefit firms that are currently ignored. This may be especially so in industries such as foundries and textiles and for technology diffusion, in which scientists have little interest, and for small and medium scale industries with limited political clout.

Smaller firms have difficulties in other areas too, making disproportionately little use of foreign sources, private commercial consultants, and TIs in general. This suggests that the common focus of governments, universities, industry and research associations, and nonprofits, on provision of technological information along with more sophisticated services is inadequate for many potential clients. For firms that have little in-house expertise, the real need is for reliable advice in assessing and managing technological information, as much as for that information.

Broadening the focus of firms to encompass the world stage is likely to encourage innovation. Innovation may as much follow as allow entry into world markets. This suggests that an important role for TIs is to help domestic firms breach international markets in addition to helping them innovate. Government policies aimed at integration with the world economy can help strengthen domestic technical expertise.

CHAPTER 4:

MAKING TECHNOLOGY INSTITUTIONS WORK

Introduction

This chapter highlights the lessons of experience for effective TI performance. Its conclusions rely principally on the survey results, but also on case studies and the historical analysis of institutions and technology advance in the countries and sectors examined.

The suggestions for TIs depend on the culture of the country, the role of the TI, and the sector involved. Having appropriate, quality staff is necessary, but staffing needs varies by type of institution and sector: the skills needed for improving a foundry training and testing center in Mexico cannot be the same as for a pharmaceutical R&D center in China, even if the principles of management are.

Broadly the findings are similar to those in numerous management studies of business enterprises. TIs must have a service orientation, know their clients, be focused, know their capabilities, including strengths and weaknesses, and orient their organization and activities accordingly. They also need to identify the innovations influencing their client industries future and design programs, accordingly, to build the capabilities required.

The government's most important role is to ensure that the business environment is competitive, so that industry is constantly seeking to maintain its competitiveness and improve its technology. It must ensure institutional support for technological development and see to it that TIs and mechanisms exist to respond to failures of the market and impediments to competitiveness. It should also create incentives for firms to use TIs and other sources of technology effectively. The government is particularly important for encouraging the development of specialized support and institutions for small scale industry (SSI). And it should be catalytic rather than managerial in all these endeavors.

What Constitutes Good Performance?

An effective TI reaches out to serve its clients and foresees their future needs so that it can serve those as well. It can adapt to changes in industry and competition.

The particulars will vary according to the services the TI provides and the sectors and circumstances in which it operates. For example, a national applied research laboratory for machinery automation (including machine tools) will need to master a range of machines, become familiar with the industries its clients serve, stay abreast of relevant and rapidly changing aspects of information technology (IT) and inform clients of the technological directions of their competition. Much of this goes beyond the daily work of responding to clients' particular needs and problems, such as attaching automation equipment to jacquards and lathes, testing the reliability and the precision of the machines and training operators and maintenance personnel.

In contrast, a well functioning productivity center for SSI might offer two services: training and problem-solving on technical and organizational issues. To the extent that most SSI are labor intensive, much of the TI's work will relate to industrial engineering and business and financial management. As industry develops and wages grow (as has occurred in Taiwan and Korea), more of the center's activities will be concerned with machinery, automation, quality control, and standards.

Standards institutions in most countries have evolved from setting and enforcing safety standards (often at a level below industrialized countries). A good institute helps companies reach export standards through outreach, training and other mechanisms and works to make local standards compatible with export market norms. It also helps industry reach quality management standards, like the ISO-9000 series.

Most TIs offer multiple services. Measures of success include clients' use of and satisfaction with services. Revenue from clients is an indication of the services' value, but it should be tempered by a TI's need to work on future issues and develop capabilities for which clients are not likely to pay directly. Another indication of its effectiveness would be a combination of how it has changed and demonstrated its "dynamism" in the past, and how it has trained staff and changed cultures to adapt to new industry requirements.

How TI Managers Can Improve TI Performance

The art of running a TI is not altogether different from that of running any other business. Both must know and reach their markets, and have products the market wants today and will need tomorrow. In a skills-based service institution or business, management must be able to recruit, develop and keep the right people. For TIs that means high quality technical people. It also needs a "user friendly" approach to its work and to bring in outside ideas and people to broaden the awareness of the TI and prevent its stagnation.

Management must be clear who their clients are, so that they can match their resources to client needs. This is particularly crucial for publicly supported TIs. Too often the definition of the clients varies according to the audience. Consider a typical national TI whose vision statement includes an entire industry or range of industries as "clients." For politicians, the clients are the small firms and the region where that same TI is located. For the TI's scientists and engineers, the most dynamic firms are perceived to be the clients, as they are most likely to be able to absorb technology or communicate with them. Ultimately few clients are served well. Dynamic, aggressive firms get some of what they want, but most SSIs are inadequately attended. Rarely can hi-tech, large firms and labor-intensive smaller firms be properly served by the same TI. Box 3 illustrates the manifestation of this problem even in well regarded TIs.

SSIs in particular require special TIs; otherwise they obtain little or no support. But the same point ap-

Box 3

Problems with the Best and Brightest

In the survey, firms were asked to name TIs and associate particular benefits and problems with them. In Korea and Taiwan two themes emerged that were not unique to those economies. First, TIs cited as providing excellent service were also roundly criticized (by fewer but still significant numbers of firms) for high fees, slowness and complex procedures, and impractical technical know-how. Second, large, well regarded R&D centers such as the Korean Institute for Science and Technology (KIST) and the Industrial Technology Research Institute (ITRI), with their recognized scientists and engineers, were generally not considered effective in working with small firms.

These results are not unexpected. KIST and ITRI scientists are often at the forefront of their disciplines and well regarded overseas. They prefer to work on state-of-the-art problems of interest only to the most technologically advanced, generally larger firms or on projects of their own creation.

At the same time these institutions receive preferential funding and some of their researchers are preceived to be spoiled and arrogant. Their usefulness to the economy is consequently hotly debated. Diffusion of technology and more basic problem-solving do not excite their scientists and engineers, but simple applications are what most firms require.

These centers can and do serve as depositories of technological capabilities that produce technological synergies, economies of scope and scale, and a more dynamic work environment. They should not be expected to carry out functions such as supporting a labor-intensive, small-enterprise dominated sector for which they are ill-suited. They, must, however, be more accountable to the society, earn more of their resources from industry, and be more responsive to clients.

Source: Global survey results and interviews by Kee Young Kim and San Gee.

plies widely. If the TI's clientele and focus are clear, then the technical staff can use their skills appropriately and prepare to address future problems. For example, a textile technology center that attempted to cover all aspects of textile production and all sizes and shapes of producers lost sight of the effect of information technology on textile mills and was unable to help its client mills prepare for competition in overseas markets.

TI management should encourage a range of approaches to ensure that their technical staff know their clients and the clients' needs. Effective TIs provide a range of services that incorporate many means for client interaction, including extension programs, open houses, surveys and seminars. When these activities were all extensively used, the survey found that TI performance improved significantly. Having multiple programs of industrial interaction is an integral part of the work in effective TIs, where good scientists get involved in these activities, learn about their clients and problems, and sometimes redirect the longer term projects in light of the market.

Another way of keeping in touch with clients is doing work for them. Generating income from clients makes TIs more practical. The practical activity of India's National Chemical Laboratory has grown along with its contract revenues--which grew from less than 20 percent to about nearly 40 percent of total revenue in five years and have exceeded one half of operating expenditure over the past two years (see Box 9 in Chapter 5).

Certain formal aspects of client orientation and association did not seem to affect performance. In particular, formal organizational links with industry by themselves, such as membership on boards of advisers or directors, seemed to have no impact on the quantity of TI services provided to industry. Similarly, whether the CEO of the TI came from industry or research seemed to make little difference on performance (except that an industrial background of a CEO did on average add 20 percent to industrial contract earnings). Perhaps these findings illustrate that client orientation must be internalized. Superficial links by themselves will not suffice. Only when the client orientation was seriously manifested did performance improve.

A TI manager should attend seriously to rejuvenating the institution's capabilities. Ways in which this can be accomplished are through training and exposing staff to relevant new technological developments and industrial programs abroad, sabbaticals, sending staff for periods to work in industry and bringing in visiting industrialists, lecturers and researchers. The dynamic quality of TIs surveyed was enhanced dramatically by exposure to the outside. Again, TIs are similar to firms. TI staff need to be exposed to the outside world, to visit trade fairs and conferences and receive their equivalent of technical training.

Survey results suggest that incentives matter, and they will vary from country to country. Essentially they should encourage technical staff to be client-oriented, stay on top of their field, and work in teams. Staff advancement based partly on practical achievement and contribution to income seemed to have the impact intended. Such incentives schemes are important tools for encouraging client-orientation and income generation, provided society's norms permit this sort of differentiation in staff remunerations.

Technical staffing must match the vision and role of the TI. It makes no sense to seek theoretical scientists to staff a standards, testing and problem-solving laboratory for machinery industries. But good mechanical engineers, materials scientists, and technicians are needed. Firms' most frequent criticism of TIs is their failure to solve technical problems.

Two illustrations show good TI practices for different markets, roles and sectors. One type is a national laboratory in a science-based sector. The leadership of a chemicals R&D laboratory, to serve the budding chemicals, plastics, pharmaceutical, fertilizer, and polymer industries, must have a staff that can foresee developments. It needs chemists and chemical engineers that can help design polymers and other new chemicals, advise on process, and carry out pilot-scale experiments.

Some will need experience in technologically advanced multinational companies, and a few should have carried out internationally recognized research. Confidential work for some clients will include testing and information searches, helping adapt imported processes to local equipment and/or materials, and designing polymers. The laboratory will also advance technology by, for example, developing know-how and products in advanced engineering polymers, or engaging in research with a university in an advanced country. Perhaps one-third of its budget will be devoted to these types of projects, funded by research councils and government and industry organizations. The other two-thirds would emanate from projects and services-testing, training, contract R&D-for mostly domestic industrial clients.

A second well-run TI supports a cluster of small scale firms in a mature sector in a region. Serving the local foundry and machinery industries, the TI will be staffed by engineers who understand industrial process, production organization, and materials. Staff will frequently visit clients to identify and interpret their problems. Testing, information provision, and trouble shooting are its main activities. The staff might spend 15 percent to 20 percent of their time at a national metallurgical center or a university mechanical engineering department to learn about developments in other parts of the country, and every year at least one staff person will spend time abroad learning about processes, materials, and research in advanced countries. Perhaps a small amount of R&D is supported by a research council and the local industry association, who also might support regular visits and collaboration by outside lecturers and researchers at the TI. Clients pay a large part of the cost of services, but the local and national governments subsidize some activities, including training, technical exchange with other institutions-perhaps a quarter of the budget.

Variations by Sector and Technology[6]

Sectors vary by the nature of their key technologies, whether they are mature or emerging, rapidly or slowly changing, sophisticated or simple, science or engineering-based, and the extent they use generic technologies such as information technology, industrial engineering, and materials. They also vary according to their economies of scale and their industrial structure--the number and size distribution of firms.

The findings suggest that effective institutions as well as policies must vary by sector. The nature of support and mix of services offered will also need to change as firms grow and become more technologically sophisticated.

Engineering industries, such as auto parts and machine tools, involve many technological areas and complex production processes that can be mapped and disaggregated. Most innovations (product or process) are small and incremental and normally only affect part of the production line. They can emanate in many ways from many sources. Most are not proprietary, and the few exceptions are frequently better kept as trade secrets than patents. Hence patent regulations are not major factors in these sectors. Firms or countries that are far behind the frontier have many opportunities to obtain technologies, skills and advice cheaply. But most innovations require the firm to have technological capability to build upon. Not all innovation, however, need be carried out within the firm. Wide-ranging scale economies can be obtained by collaboration and joint learning (see Boxes 4, 5 and 6 for example).

Engineering industries are built on a wide technological base, and therefore need a range of TIs. Some specialize in a sector, others in industrial or production

6 This section relies on the contributions of Greg Felker, a doctoral candidate at Princeton University.

engineering and work with firms in many sectors. Large government-run national laboratories are not normally relevant. In auto parts, for example, advanced research labs are more likely organized by or with an assembler.

In science-based sectors much of the technology is codified, and if it is to be understood or improved, scientists need advanced training and equipment. Pharmaceuticals and polymers are two such sectors. Patent protection and economies of scale are important considerations in pharmaceuticals because of the high cost of developing, testing and marketing drugs. In pharmaceuticals, India and Hungary[7] illustrate that high-level government support can help build underlying capabilities. Both countries had relaxed intellectual property regimes, and built public-sector corporations and research institutes. While few new drugs have been developed, many were reverse-engineered, and processes were developed for existing pharmaceuticals. In India's rapidly growing sector, some entrepreneurs and managers were trained as engineers in public-sector companies before a "modern" pharmaceutical sector existed. Whether companies in either country can make it into the big leagues is questionable, but multinationals are already tapping the local talent.

Polymers have some similarities to pharmaceuticals, but developing a polymer is much quicker and requires no extensive trials.[8] The returns to scale are in the production process, and changes usually come in an entirely new plant or product. Efforts in Japan to build research associations to carry out joint R&D by and large failed. In India by contrast, national R&D centers have helped firms develop polymers and solve material problems. The interests of companies and scientists seem to converge. Companies are interested in making products and profits from the intellectual property, and scientists want to work on complex chemical and material problems with the aim to publish eventually.

In sectors where the technology is mature, changing slowly and largely not proprietary--some engineering sub-sectors, foundries and textiles--there are many opportunities for using TIs to diffuse known technologies widely and thus offer scale-economies for technology transfer. Instead of companies importing know-how individually, the TI imports and transfers it to many companies. Sector studies of Japanese foundries, Chinese textiles and Korean auto parts illustrate this. Textile research associations (see Box 4), Japanese-type business associations (see Box 6) or cluster-type technology service organizations are models for different circumstances.

These cluster-type technology transfer organizations are likely to be most relevant for early industrializers since industrialization normally starts in sectors with mature technologies that use unskilled, low-cost labor and tends to develop in selected regions.

Cooperatives

Cooperative research associations (RAs) are most commonly found in the textile sector. Box 4 presents an example from India, but relatively successful examples can be also found in other surveyed economies, including Taiwan, as well as all over Europe. Cooperatives are generally difficult to organize. Companies need to perceive that they stand to benefit more than they risk by joining together with their competitors. The promoter should be a leader trusted by competing firms. In textiles, comparable companies may join together, as the perceived competition may be largely from foreign companies, whether in domestic or foreign markets. And the perception of foreign competition may be needed to

7 Insights concerning pharmaceuticals are based on the work of Professor Shekhar Chaudhuri of the Indian Institute of Management in Ahmendabad, India and Ms. Katalin Gyorgy of the Budapest University of Economic Sciences in Hungary.

8 This section owes insight to Professor Shinichi Watanabe of the International University of Japan and to Fumio Nishikawa, an industrialist and an advisor to the study.

spur the formation of cooperatives. Many textile manufacturers compete domestically on design and quality, based on trade secrets and employee expertise. In those circumstances, firms see a joint need to stay current on processes and design, to share testing facilities, and to help firms solve their problems. Of the 150 TIs interviewed in China, Japan, Korea and India, twenty-one were cooperatives (with or without government involvement). Of those, eleven were in textiles[9], and the rest were spread among software, pharmaceuticals, synthetic rubber, auto parts and textile machinery. Interestingly, although there were no cooperative RAs in foundries Japanese business associations (akin to RAs) were an important component of Japan's catching-up phase in foundries (see Box 6). Cooperatives take on many forms; an example of a club-like *keiretsu* cooperative in auto parts is presented in Box 5.

Box 4

Cooperatives: A Relative Success Reflects Potential and Pitfalls

Cooperatives have the advantage of having captive industrial clients and interest but must be service oriented to survive—members will stop paying dues and purchasing services if they get no value. Cooperative TIs more frequently suffer from inadequate funding from members after the initial stage of cooperative spirit and the passing of the motivation for their founding. Industry will fund projects that have an identifiable early benefit. Beyond that, even successful cooperatives have had trouble supporting R&D in new areas.

The Ahmedabad Textile Industry Research Association (ATIRA) in India was modeled on the British Research Association, in which industry and government joined forces for technological cooperation. A couple of far-sighted large mill owners mobilized the backing of industrialists, government, and technical staff. ATIRA offers the full gamut of services—training, testing, consulting, R&D—and is considered well-run.

In its fifty years, ATIRA has changed with the textile sector. Its role has varied over time on a narrow band of providing services to industry and attempting to lead industry into the technological future. Like many TIs, it has had difficulty integrating its various roles, and its high-level staff have been more at home doing basic research that "reinvents the wheel" than anticipating the implications for its members of technological advances and changes in trade rules and patterns.

Until recently, its sources of revenues varied only modestly. Roughly a fourth each has come from government grants, membership dues, services to industry and sponsored research, largely from government and international agencies (like United Nations Development Program). Untied government grants are now being phased out, and services are being emphasized. ATIRA is also likely to rely more on consortia of key members to sponsor R&D and build new capability, as government and international aid funds become scarce. That would also encourage industry to be more involved in strategic, industrial and technological thinking. The danger, of course, is that when the going for industry gets tough, industry will cut support, particularly for the long term activities.

ATIRA's well-regarded services, organization and staff have not ensured sufficient foresight. Like many institutions, sectors and countries, better mechanisms of funding and governance for TIs are required to ensure they remain responsive and provide strategic advice to their sectors and companies.

Source: Interviews and report of Dr. Shekhar Chaudhuri of the Indian Institute of Management-Ahmedabad.

9 There is no evidence from the survey, but the persistence of the textile coops may have been enhanced by their ability to serve as lobbyists for the members in allocating quotas. Most of the coops preceded the international textile quota arrangements.

Box 5

Keiretsu Cooperative

The Japanese auto parts industry provides an example of a cooperative TI and the evolution of TIs. Established in 1960 at the behest of the parent auto assembly company (which had its own large R&D lab) and key first-tier parts suppliers, this automotive TI has grown to 919 staff. Seventy-five percent are technical specialists, performing a range of activities, with advanced and contract R&D being most important. The TI is closed to outsiders, working with and sharing information only among its forty members (the auto maker, nine first-tier suppliers and thirty secondary suppliers). Work comes by individual or joint contract, through technical advisory groups in a range of fields covered, and from the ideas of R&D staff. Most of the budget is financed from membership fees; less than ten percent is from service fees.

The nature of TI activities evolved from information exchange to joint projects on fuel efficiency and emission controls after the 1970s oil shocks, to greater contract and advanced R&D work. In contrast to public sector TIs, the automotive TI became far more important to parts suppliers, once they caught up to the most advanced in the world. Today, joint R&D is common, since members view technology sharing and alliance as helpful even as they are concerned to achieve the right balance between openness and confidentiality. The lack of openness to non-members does act as a restraint to top class researchers who prefer to share their research findings.

The TI has made major contributions in emissions control R&D and in robotics. It offers expanded approaches to problem-solving and R&D, increases the efficiency of technological development by building on synergy, and raises technological capacity among members.

Source: Based on interviews and reports of Tatsuya Ohmori of Seigakuin University and Yoshitaka Okada of Sophia University.

CHAPTER 5: GOVERNMENT ROLE IN REFORMING TECHNOLOGY INFRASTRUCTURE

Government Role in Technology Development

Government's role in TIs is, first and foremost, to create an environment conducive to technology acquisition and development, and to offer the right incentives. Regardless of ownership, firms need to operate in a competitive environment to generate concern for improving product quality, designing new products, and increasing production efficiency. TI services will then have a potential demand.

The appropriate environment also includes an education system that produces quality technical manpower, and a technology infrastructure. Government's role is to promote both but, at least with regard to infrastructure, not to manage them. Government might initiate action itself, stimulate industry to form jointly TIs, and/or stimulate an educational institution or private group to start TIs. Government can, as a catalyst, offer the right incentives and financial assistance that will stimulate growth and service to industry. For its financial contribution, government should demand results in achieving the objectives set, but avoid the pitfalls of attempting to control how they are achieved.

Where the infrastructure exists, but fails to support industry, government is frequently part of the problem. The way it finances TIs--for example, budgetary transfer for line item expenses, rather than programs--frequently acts as a disincentive to industry support, as does the control it exercises over TI activities. Successful instances of institutional transformation have had in common a "hard" budget constraint and a clear vision of the institution's role and procedures, including incentives and programs for industry and effective leadership.

An important role for government relates to small-scale industry (SSI), which is inadequately supported by TIs in almost all countries studied. Only in Japan, where an extensive technical support infrastructure is dedicated to SSIs, do SSIs use TIs (which in Japan are heavily subsidized) extensively. It is generally a mistake to tack on support for SSIs to general TIs other functions. Most SSIs have different needs and lack the technical staff to communicate with sophisticated TIs (small hi-tech firms are exceptions). TIs that focus on SSIs need to expose companies to the benefits of change and generate demand for technology improvement, as well as resolve problems brought to them.

Two approaches for supporting SSIs seem to be effective. Japanese TIs are decentralized and directed at geographic clusters of industries. They are supported by prefectural (county) governments, and their purpose is to support local SSIs. TI staff work with their clients in many ways, and most work relates to diffusion. The clustering of related industries permits TIs to specialize.

Taiwan's productivity center offers a different approach and also is successful. This center is an SSI model of a TI that develops technological expertise in a generic area with wide applicability to a range of SSI across industries. The center's expertise is industrial engineering and automation. Its services are well-regarded, but they are used by only a low percentage of the enormous number of SSIs, a rate of TI usage much lower than in Japan. A similar model is used in Korea, and is being developed in parts of China.

The Importance of a Diffusion Orientation

Diffusion of known technology to firms should be central to the work of TIs. Industry most often demands information, skills training, and solutions to problems. Their needs can be met by those with appropriate technical background. Even where the need is to learn an entire technological package (as when it is imported), the country or company must consider how to train its staff, companies or subcontractors to become thoroughly familiar with the know-how involved, as well as to ensure adaptation.

Japanese business associations illustrate how imported technology can be diffused to catch up with foreign competitors. Business associations imported and diffused various metal castings (foundries) technologies in the 1950s and 1960s (Box 6). An association may license a foreign process, master it and then sublicense it to member firms. Or, once the patents or licenses lapse, an association may sublicense a technology from the original licensee, then adapt and diffuse it to subcontractors of the original licensee. By becoming the loci for mastering technologies, the associations can improve them or carry out R&D in related areas.

> *Box 6*
>
> **TIs For Catching Up**
> ***Japanese Business Associations***
>
> To transfer, assimilate and diffuse foreign technologies, groups of Japanese companies, with and without government help, organized various institutional arrangements. The Japan Business Association (BA) was one type of TI. BAs were widely used in foundries.
>
> The Japan Shell Molding Association was set up by twenty-six firms in 1956 to import as sole licensee shell molding technology and disseminate it to its members. By 1961 it had about 250 members and had acquired and disseminated many other technologies.
>
> On the other hand, Toshiba licensed the technology for spheroidal graphite cast iron from a U.S. company and developed the process. Once the patent expired, the Japan Ductile Cast Iron Association was set up to disseminate cast iron technology and carry out related R&D. An Association member used centrifugal casting to apply spheroidal graphite cast iron to pipes.
>
> Direct transfer within *keiretsu* by an importing firm, as well as by prefectural institutions to small-scale industry independent of *keiretsu*, are other mechanisms for diffusion.
>
> *Source:* "Catching Up to Leadership," by Ms. Sakura Kojima, Tokai University, and Professor Yoshitaka Okada, Sophia University, Tokyo, Japan.

TIs then can play a major role in facilitating import and absorption of foreign technologies, but to do so, they must quickly learn the art and legalities involved in intellectual property and confidentiality. Business associations, used extensively in castings, could not be used successfully in every sector in Japan. They were not used for polymers; chemical companies in the U.S. and Europe guarded their technologies and did not permit easy sublicensing. The lack of associations may also reflect the complexity and the science basis of polymers. Associations would not attract the talent normally found only in basic research laboratories or in the R&D labs of advanced chemical companies. Narrow research associations have also failed in Japan's polymer sector. They lacked the wide chemistry and chemical engineering talent of broader basic research labs.

Diffusion for Small Firms

Diffusion encompasses the use of machinery, the application of quality enhancing systems (even management practices and information technology), the solving of familiar problems, technical training, the testing of products and materials, and the provisions of technology, standards and related information, in books, by people or on line.

Even organized, large companies, with significant technical know-how, have difficulty keeping abreast of their fields. For small and medium-sized firms, it is difficult to know the questions to ask. It is not enough for a TI to support small firms. They need organizing principles and expertise-specialized skills such as industrial engineering for a range of industries, or experience in one or more sectors in a region. Successful examples of the cluster approach are Japan's prefectural R&D centers, while

Taiwan's productivity center applies its specialized capabilities in industrial engineering and automation across small-scale industries.

Which approach is suited for an economy depends on many factors: the size of the sector, the structure, and the institutional culture, including the feasibility of industrial firms working in cooperatives. And the two types of TI orientation for SSI are not mutually exclusive. Taiwan has sector-specific TIs that compliment its productivity center. As the sector grows, technological needs become more diverse, and the institutional requirements become greater.

Even diffusion-focused institutions need to be forward-looking. Garment, electronics, and castings firms must be able to compete as wages rise and buyers demand higher quality. TIs specializing in small firms must stay abreast of developments in their areas, or they will stagnate, and demand for their services will decline.

Reforming or Restructuring TIs

In most countries TIs are established by the government to build the nation's knowledge base and develop technical manpower, as well as assist industries that are not ready to pay for know-how and technological information. After investing in the TI infrastructure, however, many governments find that its contributions to development remain minimal and its technological expertise is of limited practical relevance to industry. TI managers need to bridge the communication gap between owners and managers in industry, who may be sophisticated technology users but use obsolete technologies, and their own scientists and engineers who are interested in cutting-edge problems and research.

When TIs become divorced from the needs of industry, firms are tempted to curtail support for them. On the other hand, governments are hesitant to close the door on a national resource, especially one that could help improve the country's competitive position. For this reason, governments are increasingly interested in reform of TIs. Results have frequently been disappointing. Partial solutions--setting up a marketing arm for TI innovations, changing the charter and composition of the TIs' board, or adjusting project selection criteria--do not alter the incentives that shape TI activities.

Successful restructuring is feasible in most situations. There is no simple formula for TI reform, and the approach will depend on many internal as well as external factors. The key is to understand the TI's clients, how to reach them, and how to support them. Sometimes ownership, but more often internal incentives, legal structure, management, and the direction of programs, need change.

A common weakness is that a TI is funded entirely or largely by government, without any mechanism to ensure that it is serving well-defined clienteles. Staff rewards are based principally on criteria like publications and research recognition, that are unrelated to client services. Priorities are then set by the scientists, who generally have never worked in industry. This may be appropriate for basic research, but not for assisting industrial clients. Another weakness stemming from the TI's "insularity" is the frequent lack of understanding of the impact of a more open, competitive market on the needs and competitiveness, including technology and product quality of local industry.

Three cases demonstrate the routes to reform. The Industrial Technology Research Institute (ITRI) in Taiwan (Box 7) illustrates how effective restructuring is possible by changing leadership, funding and project approval process, without altering the structure.

China chose another route to reforming more than 5,000 TIs belonging to various government ministries, municipal and local authorities, and state enterprises. Government squeezed their budgets and decentralized decisions to authorities and to the TIs. Some TIs have down-sized; others have set up spin-off plants, and some have become demand-driven by serving well-de-

Box 7

Changing Directions in Taiwan (China)
The Industrial Technology Research Institute

The Industrial Technology Research Institute (ITRI) was formed in 1973 from three TIs to serve as the premier TI of Taiwan. ITRI was to lead technology development and carry out advanced R&D beyond industry's capability. Funded entirely by the government, ITRI grew isolated from industry and, except for a few instances of absorbing and transferring imported technology (for example, it helped set up Taiwan's first integrated circuit producer and designer in 1979 and 1982, respectively), it ignored industrial demand. ITRI worked in metals, chemicals, mechanical engineering, mining and energy.

In 1982 the government initiated reforms. To lead the organization it recruited an experienced researcher with industrial experience abroad, pushed for financing from clients, and insisted that the bulk of government funding would be on a contractual basis--researchers had to submit concise strategic proposals outlining why a project should be undertaken, identifying potential clients for the results, and proposing budgets and timetables. Proposals are assessed by a technical group from industry, academia, and government. Researchers are expected to live with their commitments. Today ITRI is considered one of the most successful TIs in supporting industrial development. By the early 1990s, only 5 percent of the budget comes in untied government disbursements. Half comes from industry contracts, and the remainder from government contracts with long-term links to industrial development.

Source: Based on interviews cerried out by San Gee of the National Central University in Taiwan.

fined clienteles. There have been costs. Some talented staff have quit, and a number of institutions have closed. China also fostered the creation of new institutions to fill gaps. To develop basic and strategic research, the government designated a number of national key R&D programs. The designation is competitively assigned and is meant to ensure that a portion of resources is reserved for developing long-term capability in critical technologies. The signals to TIs were unequivocal: they had to serve clients and earn a sizable portion of their budgets. The budget squeeze on most TIs was substantial. Given the enormity of the task, the Chinese Darwinian squeeze may have been the least bad option.

The squeeze in India was softer, and the results have been more modest. By Indian standards, reforms of the key group of industry-related TIs in 1988 were substantial, including encouragement of consulting by research staff, reducing (marginally) untied government funding, and mandating increases in contract income. The National Chemical Laboratory (NCL), and its polymer division in particular, did transform themselves. That, however, was a consequence of exceptional leadership, technical capacity, and a technical agenda that was not radically different from NCL's previous one, along with limited outside support. Other Indian institutions, particularly less technically able ones, have not adapted. But as salaries remain guaranteed, there is no imperative to change. Reforms since 1991 have generated increased competition and fostered increased demand for improved technology. This changed environment now calls, perhaps, for further institutional reform measures.

Lessons for Government Policy and the TI System

While the reform process is complex, success is certainly achievable if incentives can be reoriented. TIs' performance and funding, along with the advancement of staff, must be linked to the quality of service to industrial clients. Achieving this alignment depends on the industrial context. Governments with established TI systems must change budgetary and internal staffing incentives, as well as become responsive to a changed environment.

For countries with nascent industrial sectors who are just establishing a technology infrastructure, the lessons are similar. A service orientation is the foundation. In early stages, most industries are likely to demand basic, diffusion-related services. Building institutions for diffusion--standards, testing, information dissemination, training--will lay the groundwork for research capabilities. The economies of scale in technology diffusion are considerable. Governments and TIs should constantly look for opportunities to foster diffusion, whether through direct services or by stimulating

Box 8

Restructuring, Chinese-style

China's efforts to restructure its technological infrastructure have been dramatic. TIs were previously simply given a mission by their parent authority and a budget. Whatever the results, the system was slack. Beginning in 1989 the budget for more than 5,000 TIs was slashed in half over three years. The pain was not distributed uniformly; more prestigious and better-connected TIs were less affected. Coping with cuts was left to the leadership of the TIs. About one-third of the cut was funneled back through banks as low interest loans, and other funds were channeled to national programs for S&T planning or key studies. Further reforms and subsidy reductions required additional belt tightening in the 1990s.

The response by TIs has been varied. The Research Institute of Automation for Machinery Industry (RIAMB) in Beijing has weathered the cuts. Before 1989 RIAMB's work was determined by government and was largely scientist- and laboratory-driven. Even in 1986, its revenues were Yuan 12 million from government and Yuan 2 million from clients. By 1993 its budget had risen to Yuan 60 million, of which only Yuan 3 million came from government, in the form of contracts. It has obtained thirty patents, won thirty national and international prizes and eighty ministerial prizes. It has diffused many technologies all over China and solved many problems. It lost some of its most talented staff to multinationals and joint ventures and the new private sector before its salary structure was liberalized.

The Beijing Research Institute for Plastics (BRIP), established by the Beijing Municipal Government in 1964 to support local plastics manufacturing firms, did not fare as well. It had to shed thirty percent of its 500 staff and reduced the pay of an additional 100 staff. It even had to rent out some of its building. It has not been able to keep up with some of Beijing's more technologically dynamic polymers and plastics manufacturers, and it has had no resources to invest in equipment and know-how. Its financial situation has improved slightly with extreme belt-tightening, and with the introduction of incentives to staff who bring in contracts. But its viability remains unclear in the long run. It could become a combination of cooperative production unit and advisor or joint venture with rural firms (township and village enterprises) that need intermediate technical know-how.

Some TIs have set up factories and dropped their institutional roles; others have become production and technology development organizations; some have shed the weakest staff or the least well-connected. Many have adopted merit salary and incentive schemes, sometimes only after losing qualified people. What is clear is that all have had to move toward market demands, whether in technological know-how or real estate. The adjustment seems to be a product of the initial endowment and the vision and capability of the leadership.

Source: Based on interviews carried out by and under the guidance of Professor Xu Zhao-xiang of the National Research Center for Science and Technology for Development, Beijing, People's Republic of China.

Box 9

Institutional Reform in India
National Chemical Laboratory

The National Chemical Laboratory has had excellent technical leadership from its inception in 1953. It was a science institute where personnel spurned practical work and considered those in academia abroad, particularly in the U.S. and U.K., their peers. Like many TIs in India, it was huge and its work was of mixed quality, although some of its research was world-class and was published in international journals. It is located in an industrial city, with a pleasant climate and good schools--an attractive place for scientists to work and live. Major areas of concentration are catalysis, biochemistry, organic chemistry and polymers.

Through the 1970s and 1980s the chemical industry was maturing, but in the late 1980s, NCL was doing only a small portion of work for industry, earning slightly over 20 percent of its operating budget from contractual services, much of it with government. Contracting with industry was not valued like publications, and there were no monetary or other incentives for doing anything beyond publishable work. Externally, however, the role of TIs like NCL was being questioned, along with their automatic funding at a time of budgetary stringency.

Government reforms (based on the controversial but highly regarded Abid Hussein Commission report) beginning in 1986 included restraining budget support, setting guidelines for contract revenue performance, and authorizing monetary incentives to staff for contractual work. Following those policy changes and the appointment in 1988 of a new director, NCL rethought its vision and business plan and secured a (World Bank financed) loan to help develop its practical capability. It hired consultants to help set its priorities and instituted a reward system that values industrial service, team effort and income generation, while still supporting outstanding science. It is seeking a balance of foreign and Indian industrial contracts, so that it remains at the forefront of its field at home and abroad. Revenues have climbed: contract revenues have exceeded 50 percent of recurrent expenditures over the past two years. The success of the institute is so widely recognized that in 1995 the director was appointed director-general of India's network of scientific and industrial laboratories whose forty TIs include NCL.

Source: Based on interviews carried out by Professors S. Ramnarayan and Shekhar Chaudhuri, Indian Institute of Management, Ahmedabad, India.

the private sector to exchange information through business associations, sub-contracting networks, or other forms of private sector organization.

The evidence is overwhelming that a country's industrial development benefits from a well-designed technology infrastructure and policy that aim to meet the needs of the range of industries and firms. TIs can complement, substitute and facilitate industry efforts, and they can promote efficient use of scarce technical resources. However, they must be structured, staffed and funded to support industry's needs including those of smaller firms. The study has illustrated various, but all too rare, successful institutions helping smaller firms develop technologically. However, the institution and program models need to be appropriately refined, adapted and experimented with, before applying them in the vast majority of inadequately served countries.

REFERENCES

Amsden, Alice H. 1989. *Asia's Next Giant: South Korea and Late Industrialization.* New York: Oxford University Press.

Arnold, E., J. Bessant, M. Hobday and H. Rush. 1993. *Background Benchmark Study for the Venezuelan Institute of Engineering.* Brighton.

Bell, Martin R. 1984. "Learning and the Accumulation of Industrial Technological Capacity in Developing Countries." In Martin Fransman and Kenneth King, eds., *Technological Capability in the Third World.* New York: St. Martin's Press.

Bell, Martin R. 1993. *Integrating R&D with Industrial Production and Technical Changes: Strengthening Linkages and Changing Structures.* Science Policy Research Unit, University of Sussex, Brighton.

Branscomb, Lewis, et al. 1991. *Empowering Technology: Implementing A U.S. Strategy.* Cambridge, Mass.: MIT Press.

Braunling, Gerhard. 1986. *Publicly Funded Organizations Assisting Innovation and Technology Transfer in Small and Medium Sized Companies.* Luxembourg: TII.

Dahlman, Carl J., Bruce Ross-Larson, and Larry E. Westphal. 1985. *Managing Technological Development: Lessons From the Newly Industrializing Countries.* Washington, D.C.: The World Bank.

Dahlman, Carl J., and Ousa Sananikone. 1990. *Technology Strategy in the Economy of Taiwan: Exploiting Foreign Linkages and Inventory in Local Capacity.* World Bank Technical Paper. Washington, D.C.

Dertouzos, Michael L., Richard K. Lester, and Robert M. Solow. 1989. *Made in America: Regaining the Productive Edge.* Cambridge, Mass.: MIT Press.

Ergas, Henry. 1986a. *The Importance of Technology Policy.* Paris: OECD.

_____. 1986b. *Does Technology Policy Matter?* Centre for European Policy Studies, Paper No. 29.

Ernst, Dieter, and David O'Connor. 1989. *Technology and Global Competition.* Paris: OECD.

Fransman, Martin. 1990. *The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System.* Cambridge, England: Cambridge University Press.

Fransman, Martin. 1986. *Technology and Economic Development.* Boulder, Colo.: Westview Press.

Fransman, Martin, and Kenneth King, eds. 1984. *Technological Capability in the Third World.* New York: St. Martin's Press.

Freeman, Christopher. 1988. "Japan: A New National System of Innovation?" In Giovanni Dosi Christopher Freeman, Richard Nelson, Gerald Silverberg, and Luc Soete, eds. *Technical Change and Economic Theory.* London: Pinter.

Goldman, Melvin. 1994. "Technology Institutions: When Are They Useful? Lessons from Europe." The World Bank, Asia Technical Department. Washington, D.C.

Goto, Akira, and Ryuhei Wakasugi. 1988. "Technology Policy." In Ryutaro Komiya Masahiro Okuno, and Kotaro Suzumura, eds., *Industrial Policy of Japan.* Tokyo: Academic Press, Inc.

Hobday, Michael. 1995. *Innovation in East Asia: The Challenge to Japan.* Aldershot, UK: Edward Elgar.

Kakazu, Hiroshi. 1990. "Industrial Technology Capabilities and Policies." *Asian Development Review* 8, No. 2

Kech, Otto. 1993. "The National System for Innovation in Germany." In R. Nelson ed., *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.

Kodama, Fumio. 1991. *Analyzing Japanese High Technologies: The Techno-Paradigm Shift*. London: Pinter.

Lall, Sanjay. 1987. *Learning to Industrialize: The Acquisition of Technological Capability by India*. London: Macmillan Press.

Levy, Jonah, and Richard Samuels. 1992. "Institutions and Innovation: Research Collaboration as Technology Strategy in Japan." Science, Technology, Management. MIT Japan Program. Cambridge, Mass.: MITJSTD.

Meyer-Krahmer, Frieder. 1990. *Science and Technology in the Federal Republic of Germany*. Harlem: Longmans.

Meyer-Krahmer, Frieder, and Philippe Montigny. 1989. *Evaluations of Innovation Programs in Selected European Countries in Research Policy*. Karlsruha, Germany: ISI.

Mody, Ashoka. 1989. "Institutions and Dynamic Comparative Advantage: Electronics Industry in South Korea and Taiwan." Washington, D.C.: World Bank/IENIN.

Najmabadi, Farrokh, and Sanjaya Lall. 1995. "Developing Industrial Technology: Lessons for Policy and Practice." Washington, D.C.: World Bank/OED.

Nelson, Richard, and Sidney Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge: Harvard University Press.

Nelson, Richard, ed. 1993. *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.

Okada, Yoshitaka. 1990. "Technological Development and Growth of Japanese Integrated Circuit Firms: An Exploratory Study." Center for Japan-U.S. Relations Working Paper No. 5. International University of Japan.

Organization for Economic Cooperation and Development. 1992. "Technology and the Economy: The Key Relationships." Paris.

Pavitt, Keith. 1984. "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory." *Research Policy*, No. 13, pp. 343–373.

Priore, Michael J., and Charles F. Sabel. 1984. *The Second Industrial Divide*. New York: Basic Books, Inc.

Ramesh, Jairam, and Charles Weiss, Jr., eds. 1979. *Mobilizing Technology for World Development*. New York: Praeger Publishers.

Rosenberg, Nathan. 1990. "Science and Technology Policy for the Asian NICs: Lessons from Economic History." In Robert E. Evenson and Gustav Ranis, eds., *Science and Technology: Lessons for Development Policy*. Boulder, Colo.: Westview Press.

Ranis, Gustav. 1990. "Science and Technology Policy: Lessons From Japan and the East Asian NICs." In Robert E. Evenson and Gustav Ranis, eds., *Science and Technology: Lessons for Development Policy*. Boulder, Colo.: Westview Press.

Schimank, Uwe. 1990. "Technology Policy and Technology Transfer from State Financed-Research Institutions to the Economy: Some German Experiences." *Science and Public Policy*, vol. 17, no. 4, pp. 219–228.

Schmitz, Hubert. 1993. *Small Shoemakers and Fordist Giants: Tale of a Supercluster*. Discussion Paper 331. Brighton, England: University of Sussex, Institute of Development Studies.

Simon, Denis Fred. 1992. "Taiwan's Emerging Technological Trajectory: Creating New Forms of Comparative Advantage." In Denis Fred Simon and Michael Y.M. Kau, eds., *Taiwan: Beyond the Economic Miracle*. Taipei: M.E. Sharpe.

Tassey, Gregory. 1992. *Technology Infrastructure and Competitive.* London: Kluwer Academic Publishing.

Wade, Robert. 1990. *Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization.* Princeton, NJ: Princeton University Press.

Westphal, Larry E., Linsu Kim, and Carl J. Dahlman. 1995. "Reflections on The Republic of Korea's Acquisition of Technological Capability." In Nathan Rosenberg and Claudio Frischtak, eds., *International Technology Transfer: Concepts, Methods, and Comparisons.* New York: Prager.

Womack, James P., Daniel T. Jones, and Daniel Roos. 1990. *The Machine that Changed the World.* New York: Rawson Associates.

Westphal, Larry E., Yung W. Rhee, and Gary Pursell. 1984. "Sources of Technological Capability in South Korea." In Martin Fransman and Kenneth King, eds., *Technological Capability in the Third World.* New York: St. Martin's Press.

Westphal, Larry E., Yung W. Rhee, and Gary Pursell. 1981. "Korean Industrial Competence: Where It Came From." World Bank Staff Working Paper No. 469. Washington, D.C.

Reports from the Institution and Policies for Industrial Technology *Development Study.*

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Landry, Rejean. 1994. "Technological Services Provided by Institutions to Canadian Manufacturing Firms." Research Group on Government Interventions, Political Science Department. Quebec, Canada.

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Xu, Zhao-xiang, Wang Huijiong, Lu Wei, Tang Shi-guo, Chen Xiao-Long, Ma Chi, Yang Tien-zheng, Zhao Jie. 1994. "Policy and Institutional Priorities for Industrial Technology Development." Beijing: Center for Science and Technology Development. Beijing: Center for Science and Technology Development.

Wang Huijiong and Lu Wei. 1995. "China's Textile Industry: A Profile of Development and the Impact of its Technological Institutions." Development Research Center, State Council. Beijing, People's Republic of China.

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György, Katalin. 1997. "R&D and Cooperation in the Hungarian Pharmaceutical Industry." Innovacios Kutato Kozpont (Innovation Research Centre), Budapest.

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Inzelt, Annamaria. 1994. "Institutional Support for Technological Improvement: Back to Cooperation from Rigid Separation-Hungarian Institutional Adventures in the 20th Century." Innovacios Kutato Kozpont (Innovation Research Centre), Budapest.

Mosoni-Fried, Judith. 1994. "Industrial Research Institutes in the Transition Period in Hungary." Innovacios Kutato Kospont (Innovation Research Centre), Budapest.

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_____. 1994. "Technology Development in the Indian Textile Industry: Interaction Between Government Policy, Firms and Cooperative Research Associations." Ahmedabad: Indian Institute of Management.

Chaudhuri, Shekar, and C.B. Dasgupta. 1994. "Indian Software Industry." Ahmedabad: Indian Institute of Management.

Chaudhuri, Shekhar, M. R. Dixit, S. Ramnarayan, C. B. Dasgupta, et al. 1995. "International Study on Policy and Institutional Priorities for Industrial Technology Development India," Vol. I. Ahmedabad, India. Indian Institute of Management.

Dixit, M.R. 1996. "Indian Auto Components Industry Learning to Export and Grow." Ahmedabad, India: Indian Institute of Management, 1994 (rev. 8/96).

Ramnarayan, S. 1994a. "Technology Development in the Indian Foundry Industry: A Case of Choked Potential." Ahmedabad, India: Indian Institute of Management.

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Wada, Masatake. 1994. "Contribution of Technology Supporting Institutions to Technological Innovation in Japanese Software Industry." Tokyo.

Watanabe, Shinichi. 1995. "Evolution of Technologies and Institutions: A Case Study of the Polymer Industry." International University of Japan, Nigata.

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Kim, Kee Young, Moon Il Lee, and Young Min Jang. 1996. "Institutionalization of Technology Development in the Korean Textile Industry." Yonsei University.

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