The Role of Large-Scale Government-Supported Research Institutions in Development: Lessons from Taiwan's Industrial Technology Research Institute (ITRI) for Developing Countries

By

Fareeha Yasmin Iqbal

B.Sc. (Hons) Environmental Science and Film & Media Studies
University of Stirling, UK (1999)

Submitted to the Department of Urban Studies and Planning
In partial fulfillment of the requirements for the degree of

Master in City Planning

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2003

Author ____
Department of Urban Studies and Planning
August, 2003

Certified by ____
Professor Alice Amsden
Department of Urban Studies and Planning
Thesis Supervisor

Accepted by ____
Professor Dennis Frenchman
Chair, MCP Committee
Department of Urban Studies and Planning

The Role of Large-Scale Government-Supported Research Institutions in Development: Lessons from Taiwan's Industrial Technology Research Institute (ITRI) for Developing Countries

By

Fareeha Yasmin Iqbal

Submitted to the Department of Urban Studies and Planning on August 19, 2003
in partial fulfillment of the requirements for the degree of Master in City Planning

ABSTRACT

This thesis seeks to examine the extent of the role that the Industrial Technology Research Institute (ITRI) played in Taiwan's high-technological development and whether developing countries of today can promote such development by creating similar institutional arrangements.

Literature on innovation systems was reviewed, particularly national innovation systems and the role of R&D institutions within these. Taiwan's recent economic success, deemed attributable to economic and institutional reforms in recent decades, was also studied. In depth analysis was carried out of its leading high-technological research institute, ITRI, which bridges the gap between industry and academia. Although the case of Taiwan is sometimes presented as a unique example of industrial success of an SME-based state, this thesis argues that this success was possible because the research and development process had a *large* institute at its core. One way of creating such a research scale is by merging existing institutes, a process that would result in more efficient use of capital and human resources. The case of high-technological development in Pakistan is briefly assessed in order to gauge how its existing institutions structure could be amended to allow such changes to be made.

The study concludes with the following three main points: (i) *scale* is an important factor: Taiwan's SME-based industry was able to succeed because of a large research institute at its core; (ii) in developing countries, governments decide which form of high-technology to pursue and when; thus, *timing* and choice of *sector* are important; and (iii) political leadership was seen to be important in the case of Taiwan's development in high-technology, and can play a key role in developing countries of today.

Thesis supervisor: Alice Amsden
Professor of Political Economy, Department of Urban Studies and Planning, MIT

Thesis Reader: Calestous Juma
Professor of the Practice of International Development
Belfer Center for Science and International Affairs, Harvard University

Acknowledgements

I would like to express my deep appreciation to Professor Calestous Juma of Harvard University and Professor Alice Amsden at MIT for their guidance with this thesis. I am also grateful to the following for taking out the time to make valuable contributions:

Professor Dr. Atta-ur-Rahman, Federal Minister for Science and Technology, Pakistan

Dr. Otto Lin, former Vice-President for Research and Development, Hong Kong University of Science and Technology; former President of ITRI, Taiwan

Dr. Jason Hsu, Director, International Programs, ITRI, Taiwan.

Table of Contents

Abstract ii
Acknowledgements iii
Contents iv
Acronyms and abbreviations v

Chapter 1 Introduction 1
Chapter 2 Innovation systems and institutions: reviewing the literature 6
Chapter 3 Taiwan's rise in high-tech industry 27
Chapter 4 ITRI: an overview 47
Chapter 5 Discussion 60
Chapter 6 Conclusions 80

References 83

Acronyms and abbreviations

CD-ROM	compact disk read-only memory
CEPED	Council for Economic Planning and Development (Taiwan)
CIM	computer-integrated manufacturing
CNC	computer numerical control
DO-IT	Department of Industrial Technology (Taiwan)
ERSO	Electronic Research Services Organization
FMS	flexible manufacturing system
GDP	gross domestic product (if used)
IC	integrated circuit
ICT	information and communication technology
IDB	Industrial Development Bureau (Taiwan)
IT	information technology
ITIS	Industrial Technology Information Service (Taiwan)
ITRI	Industrial Technology Research Institute (Taiwan)
LAN	local-area network
LCD	liquid crystal display
MOEA	Ministry of Economic Affairs (Taiwan)
MOST	Ministry of Science and Technology (Pakistan)
NC	numerical control
NIS	national innovation system
NSC	National Science Council (Taiwan)
OBM	own-brand manufacture
ODM	own-design manufacture
OEM	original equipment manufacture
PC	Personal computer
R&D	research and development
ROC	Republic of China (Taiwan)
S&T	science and technology
SMEs	small and medium-sized enterprises
STAG	Science and Technology Advisory Group (Taiwan)
TFT	thin film transistor
TNC	transnational corporation
VLSI	very large-scale integration

1 INTRODUCTION

Purpose of Study

This thesis seeks to examine the impact that large, government-supported research institutions can have on the development of high-technology industry in developing countries. Its recommendations are based on lessons learnt from Taiwan's experience with the Industrial Technology Research Institute (ITRI).

The goal of the thesis was to study the key elements that contributed to Taiwan's success with ITRI in order to make recommendations regarding institutional set-up for developing countries to promote high-tech industrial development. The role of the institute in promoting scientific and technological development has been given much emphasis in literature on innovation systems. This thesis asserts that within a national innovation system comprised of several institutions working together, it is important for one large institute to take the leading role and coordinate the activities of the other actors of the system, thereby strengthening the research and technical skills at a national level, and contributing to economic development. ITRI is examined from this angle; was it the leading institution where Taiwan's development is concerned? How do such institutes contribute both directly and indirectly to promote industrial development? Finally, can this model of a leading-institute-based national innovation system be applied to developing countries of today to help them develop technologically?

Background

The Rise of Taiwan

Taiwan was a poor developing country in the 1950s. In recent decades, however, it has witnessed spectacular economic growth, and is now one of the world leaders in the production and design of high-technology.[1] Many analysts

[1] According to Jacobsen (2000), the label of 'high technology' is applied to "those industries in which "'product development involves large development costs, long lead times, and considerable technological uncertainty'", relying on "'knowledge that is close to the frontiers of present-day scientific research'. These industries include computers, robotics, fiber optics, genetic engineering, aerospace, artificial intelligence, and telecommunications." Pp. 43-44.

attribute Taiwan's success to the economic reforms it put in place, which have focused on import substitution[2] and export promotion. However, some have identified the establishment of key state-partnered institutions as a factor as important as the economic reforms.[3] The roles played by these institutions, and their interactions with other institutions, it has been claimed, have had a large effect on promoting technological research and diffusing knowledge within the state. An 'innovation system' was created that, in its initial stages, helped Taiwan's manufacturers imitate the production of technology of industrialized countries. Eventually, the system moved from imitation to advanced research and development, with Taiwan becoming a leading supplier of semiconductors, consumer electronics and computers to foreign companies. Today, Taiwan's focus is innovation - i.e., breaking new grounds in cutting-edge technology, such as nanotechnology, biotechnology, and opto-electronics.

The Impact of ITRI

The Industrial Technology Research Institute (ITRI) was founded in Taiwan in 1973 as a non-profit research institution under the supervision of the Ministry of Economic Affairs. ITRI has focused on keeping track of and obtaining latest technology available globally with a view to adapting it to local needs and then spinning it across Taiwan's industrial sector. ITRI also conducts contract-based research for the private sector, provides technical training, engages in long-term research projects for the state, and provides incubation facilities to help entrepreneurs start up high-tech firms. It currently has eleven labs and research centers, and over 6,000 personnel.

ITRI has often been credited as a major driver of Taiwan's success in the production and design of high-tech manufacturing. Apart from conducting research in its own labs and centers, ITRI has close ties with national universities and research centers and the large science park based at Hsinchu (many of the firms located there are graduated of ITRI's incubator). While ITRI is an autonomous institution, it has been molded by the state: in the 1970s, the government decided which technologies ITRI should focus on and how it would go about developing these; fifty percent of ITRI's funding comes from the state; and ITRI's operations are influenced by various science plans and recommendations made by the state. ITRI also works very closely with Taiwan's

[2] The process of replacing goods or services produced outside of the country with goods or services produced within the country. It is designed to enhance the local economy.
[3] E.g., Wu and Tseng (1998).

private sector, from where the other half of its funding comes. Taiwan's two leading semiconductor firms, UMC and TSMC, are both ITRI spin-offs.

ITRI has thus played a pivotal role in bringing the various components of Taiwan's various development-related institutes together: the state, universities, research institutes and the private sector.

Research Methodology

In discerning the role that ITRI has played as an institute leading the technological development and innovation processes in Taiwan, this thesis has relied largely on extant literature and electronic-interviews. The literature pertains to analysis of Taiwan's national innovation system, and the role of various organizations within it in contributing to technological research and development in the country. It also includes analysis of ITRI as a key factor in the development of Taiwan's high-tech manufacturing sector and as a central part of Taiwan's innovation system.

The interviews are of figures from various institutional categories. People from Taiwan were asked to comment on the mechanics of Taiwan's innovation system, as well as their perception of ITRI's role within it. The people from Pakistan were interviewed in order to glean insights into problems facing innovation and research and development (R&D) in high-tech in developing countries.

Significance of the study

(i) An unprecedented, thorough analysis of the role of ITRI in Taiwan's development

Few studies have analyzed ITRI comprehensively as a leading factor in high-tech development in Taiwan. Most have tended to focus on very specific, relatively narrow aspects of its role. For instance, much has been written on the role of ITRI in promoting Taiwan's semiconductor industry. Separate studies have been conducted on links between ITRI and the Hsinchu Science Park, and on ITRI's incubator. The few comprehensive studies that have been carried out are in Chinese. This thesis undertakes the task of compiling existing information on ITRI from a wide range of angles, as well as the opinions of experts, to assess the leadership role ITRI has played in Taiwan's development.

(ii) To suggest a lead-institute model of development for developing countries

This thesis tentatively explores whether technological development in developing countries can be spurred by establishing large-scale government-supported research and development institutions. While the question is not addressed at length in this thesis, the document lays out the theoretical background for further exploration of this issue.

The need to focus on technological development in developing countries is crucial; according to Sachs (2002, p. v) it is new advances in science and technology that are required "to address the interlocking crises of public health, agricultural productivity, environmental degradation and demographic stress confronting the poorest developing countries". Science and technology, in turn, are best advanced through a smoothly working national innovation system, as will be discussed in the following chapter. Thus the issue of developing appropriate innovation systems is of crucial importance within developing countries.

Thesis organization

The next chapter examines concepts of innovation and how they relate to technological change. It will also look at prevailing views on the innovation systems approach as laid out in the literature. Lastly, it explores the characteristics of national innovation systems, with a focus on developing countries.

Chapter 3 focuses on Taiwan. It looks at Taiwan's economic growth over the past four decades, its success in the manufacturing and electronics industries, and at the factors that brought these about. The latter half of the chapter looks at Taiwan's national innovation system: the key actors and the relationships between them.

Chapter 4 looks exclusively at ITRI's history, research areas, structure and functions.

Chapter 5 looks more closely at ITRI's role within Taiwan's innovation system. It then looks upon the findings thus far in the light of their applicability to developing countries, briefly examining the case of Pakistan.

Chapter 6 presents some conclusions that can be drawn from the study.

Main findings

This thesis concluded that ITRI played a lead-institute role in Taiwan's high technological industrial development, and that the creation of such a *large-scale* research institute linking industry to academia was necessary given Taiwan's reliance on small and medium enterprises.

On the basis of Taiwan's experience, the study concludes that developing countries can benefit much from an ITRI-approach towards high tech development, by consolidating research institutes in order to create the scale necessary for effective research and technology adaptation. The feasibility of doing this in Pakistan was briefly studied.

For developing countries, government interventions are a key part of the development process. Regarding government intervention in high-tech development, key lessons that can be drawn are: *choice of sector* and *timing* are important. Political leadership, too, plays a crucial role.

2 INNOVATION SYSTEMS & INSTITUTIONS

REVIEWING THE LITERATURE

Just as energy is the basis of life itself, and ideas the source of innovation, so is innovation the vital spark of all human change, improvement and progress.

Theodore Levitt

Introduction

This chapter examines the concept of innovation as integral to development. It explains what is meant by 'innovation' and the prerequisites generally thought necessary for innovation to occur. It discusses the concept of innovation systems, as well as various opinions on the boundaries and workings of national innovation systems. The role of the institution within innovation systems is of particular interest throughout the chapter. It concludes with an examination of whether the usual approach towards national innovation systems holds for industrialized and developing economies alike, and briefly discusses the severe need for technological innovation in developing countries. The chapter sets a theoretical background for the remainder of the thesis, which looks in more practical terms at how innovation can be facilitated in developing countries.

Innovation and Technological Change

While classical economists such as Ricardo and Marx were aware of the microeconomic processes involved in the adoption of innovations[4], innovation theory really took off during the 1980s, and is therefore a relatively recent branch of knowledge. Although much has been written on the subject since then, no universally accepted definition of innovation seems to exist. Within innovation literature today, the definition ranges from being synonymous with technological development to the process of making any new discovery. Definitions depend upon the type of economy under consideration; innovation takes on different meanings for developing economies than for industrialized economies.

[4] See Cooper (1994), pp. 2-3. These microeconomic processes are referred to as "Schumpeterian", after the economist Joseph A. Schumpeter.

Given that definitions of innovation have arisen in the context of current global trends and processes, there is a strong emphasis on technology. As Sachs and McArthur (2002, p. 157) state:

> We are living in an age of remarkable technological change that is forcing us to think very hard about the linkages between technology and economic development. The harder we think about it, the more we realize that technological innovation is almost certainly the key driver of economic growth.

Van Dijk and Sandee (2002) have gone a step further, claiming that innovation is "virtually synonymous with technological change" (p. 1). However, this definition is context-specific; they found that African case studies yielded a broader definition of innovation that would encompass the following processes: using different raw materials or economizing on the use of raw materials or energy; improving the design or introducing a new way to finance, distribute or stock products; and changing the management of a small business. Thus for Africa they claim that the "making a different product or a product of slightly better quality" (p. 4) could be considered innovation, since this would involve the first practical use of a new, more productive technique.

This view, of linking the definition of innovation to knowledge that leads to something new or different, has also been espoused by others. Afuah (1998)[5], for instance, states that innovation is "the use of new knowledge to offer a new product or service that customers want". This stipulation of the product being desirable or useful is considered necessary to the definition of innovation. According to Porter (1990)[6], innovation "is a new way of doing things that is *commercialized* [ital. mine]. The process of innovation cannot be separated from a firm's strategic and competitive context". These definitions are in accord with the view of innovation as technological change only when such change results, according to Cooper (1994), in a general increase in surplus value, which may be identified as profits. Therefore, innovation includes a range of activities in addition to science and technology: organization, finance, and commerce (Shyu and Chiu, 2002).

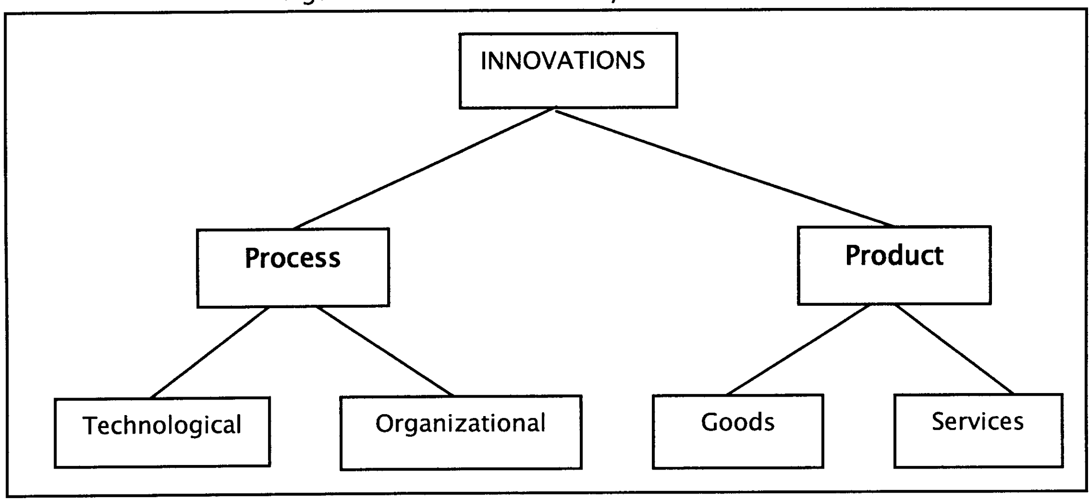
Van Dijk and Sandee (2002), among several others, have clarified that there is a difference between *product* and *process* innovation - a distinction that is made clear through Edquist's (2001) diagram (Figure 2.1) below.

---

[5] In Shyu and Chiu (2002), p. 370.

[6] In Shyu and Chiu (2002), p. 370.

Figure 2.1 A Taxonomy of Innovation



Source: Edquist (2001)

Why study innovation?

Innovation results in technological advance, which has tremendous impact on economic growth. Solow[7] conducted a study of the US economy over 1909-1949, which he published in 1957. He found that technological change accounted for seven eighths of the growth of the economy over this period, and that increases in capital stock - the equipment, machinery, and residential stock relative to the population - accounted for only one eighth of the growth of income per person in the United States.

In depicting what can happen in the absence of technological innovation, Sachs and McArthur (2002) give examples of the stagnation that occurred in the Soviet Union and many South American economies. Countries can avoid this, they maintain, by continually advancing their technological capacity. Doing this in a systematic manner would require understanding the processes of developing and applying new ideas in production, i.e., a study of innovation processes.

Edquist (2001) presents a compelling rationale for the formal study of innovation *systems*:

> ...knowledge in the form of human capital and structural capital become more important than physical capital (machinery and buildings). This would then imply that the economy *operates* in a completely different way. This should be reflected in our approaches. (p. 17).

[7] In Sachs and MacArthur (2002).

The 'systems of innovation (SI)' approach

Definition of innovation system

Edquist (2001) states that in order for a system to be termed as such, it must have *components* with *relationships* between them. Carlsson *et al.* (2002) also include *attributes* - the properties of the components and the relationships between them - in the definition of a system. Further, a system should have identifiable boundaries. However, it will be seen later that in the case of innovation systems determination of the boundaries is often difficult and depends on the level of analysis of the system.

The concept of national innovation systems was introduced in the mid-1980s by scholars who were dissatisfied with the neo-classical treatment of innovation as an exogenous variable and, drawing from the field of evolutionary economics, stressed the endogenous nature of innovation in its own development (Keller and Samuels, 2003). The systems of innovation (SI) approach was pioneered by Freeman (1987), Lundvall (1992) and Nelson (1993) and became established in a very short period of time (Edquist, 2001). It has been defined by Edquist (1997, p. 14) as: "all important economic, social, and other factors that influence the development of innovations". More specific regarding the types of innovation, Freeman (1987) defines an innovation system as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (p. 1).

It should be noted that the innovation systems approach examines the determinants of innovation, not its consequences (Edquist, 2001).

The need for a systems approach to innovation

While the results of innovation may be visible at the firm level, it is not a purely market-driven phenomenon. The process must be supported by a complex set of social institutions, both market and non-market (Sachs and McArthur, 2002). Thus in order for governments to foster innovative economic systems, they need to analyze the interconnected set of institutions that guarantee effective innovation (*ibid.*). The innovation systems approach attempts to identify the key actors involved and the relationships between them, and is therefore necessary in the formulation of any innovation strategy.

Characteristics of innovation systems

An important concept of the innovation systems approach is that learning is interactive between organizations; firms do not innovate in isolation (Edquist, 1997). This idea of the firm as a leading organization embedded within a broader institutional context has also been presented by Mytelka (1998) and by Shyu and Chiu (2002), who state that innovation is not the product of the atomistic behavior of maximizing agents, but is the result of particular dynamics determined at various levels. This view perceives competitiveness as the outcome of a continuous process of innovation that enables firms to catch up and to keep up as technology and the mode of competition change (Mytelka, 1998). Institutions are considered to be crucial elements that shape (and are shaped by) the actions of the organizations and the relations between them (Edquist 1997).

Edquist (2001) points out that all studies on the SI approach consider innovation processes to be evolutionary. This ties into the idea of cumulativeness of knowledge, another important concept of the SI approach. Current technologies and production at the firm level influence the learning processes and the nature of accumulated experience (van Dijk and Sandee, 2002). This has also been mentioned by Cooper (1994).

Sachs and MacArthur (2002) have identified the following characteristics of the innovation process that relate to the system as a whole:

1. Innovation is science-based, which implies a great deal of importance for higher education as a fundamental feature of innovation strategy. (Lall (2000) has also pointed out the highly technology-specific nature of innovation in firms).

2. It is an increasing-returns-to-scale process, which explains why scientists congregate at places like Silicon Valley and Route 128. Creating an innovation system requires creating scale. (The importance of innovation 'clusters' has also been emphasized by van Dijk and Sandee (2002) in discussing studies on SME innovation, and by Steinle and Schiele (2002)).

3. Innovation depends on market-based incentives, and on the scope of the market itself.

4. There is a fundamentally mixed public and private good nature to the innovation process. Society benefits through the widespread diffusion of (scientific) ideas.

5. Special funding mechanisms beyond the banking sector help to accommodate knowledge creation in the private sector. Innovation requires venture capitalists.

6. Innovation generates destruction of older technologies and business sectors in a process of "creative destruction". (This ties in to the "evolutionary" aspect of innovation mentioned by Edquist (2001).)

7. The innovation process is characterized by specific forms of organization that develop, test, and prove ideas. Innovation first requires networks to bring different kinds of knowledge together.

8. Many technologies exhibit characteristics of site-specifity; not all technologies can be imported from abroad since they may not all be necessarily relevant to the adopter's needs.

Lall (2000) adds the following points to the characteristics of innovation. These relate to the way the system functions:

1. Firms function with imperfect, variable, and rather hazy knowledge of technologies they are using.

2. Learning itself often has to be learned (Stiglitz, 1987). In a developing country, knowledge of traditional, stable, and simple technologies may be not be a good base on which to learn how to master modern technologies.

3. Different technologies can also have different degrees of dependence on interactions with outside sources of knowledge or information, such as other firms, consultants, capital goods supplies, or technology institutions. It is important to remember these differences in technology-specific features, which determine learning costs, risks, duration, and linkages, in considering how capabilities an be promoted by policy.

4. Capacity-building involves effort at all levels - shop floor, process and product engineering, quality management, maintenance, procurement, inventory control, outbound logistics, and relations with other firms and institutions. Innovation, in the conventional sense of formal research and development activity leading to new products or processes, is at one end of the spectrum of technological activity; it does not exhaust it.

5. Technological development can take place within a given learning process to different depths. The attainment of a minimum level of operational capability (know-how) is essential to all industrial activity. While difficult to acquire, depending on the technology and initial stock of capabilities, this may not lead automatically to the ability to understand the principles of the technology (know-why).

6. The development of know-why is an important part of overall learning. It allows enterprises to select more efficiently what new technologies they need, lower the costs of buying these technologies, adapt and improve on them more effectively, add more value by using their own knowledge in production, and develop autonomous innovative capabilities.

7. Technological learning in a form does not take place in isolation; the process is rife with externalities and interlinkages.

In his critique on the systems approach to innovation, Edquist (2001) gives various reasons why he believes it cannot be termed a "theory", as is sometimes done. Firstly, he points to the fact that the term "institution" has often been used inconsistently among various authors, i.e., both in the sense of organizational actors (or players) and in the sense of institutional rules (or rules of the game). Aslo, studies on innovation systems are weakened by the fact that very little is known about their determinants. Further, the SI approach partly neglects other kinds of learning processes than those that lead to innovations in a direct and immediate way. This issue was addressed by Lundvall (1992)[8] when he pointed out a "broad" versus "narrow" approach to innovation. Edquist (2001) also claims that the SI approach largely neglects individual learning in the form of education, and that it lacks a "theoretical" component about the role of the state. This last flaw, he claims, is an important neglect, since the state and its agencies are obviously important determinants of innovation in any SI.

Stages of innovation

Van Dijk and Sandee (2002) have identified four stages of technological change: the introduction of new technology, the imitation of technology, adaptation of the technology to local circumstances, and further development of the technology by local producers.

[8] In Freeman (2002).

Most of the procedures above relate to technology adoption, rather than an actual innovative process. Thus there are two basic modes of advancing technology (Sachs and McArthur, 2002): *innovation* (developing one's own new technologies) and *adoption* (introducing technologies that have been devised elsewhere)[9]. All economies pursue both to an extent. Adopting technology from abroad may raise living standards substantially, and even achieve long-term growth based on continuing technological innovations abroad. However, such an approach also has its limitations; economic theory demonstrates that if one economy is a technological innovator while another economy is a technology adopter, the innovator will maintain a lead in income per capita relative to the adopter. Further, this income gap between the two economies will persist over time even if the technology adopter ends up incorporating all of the technological advances made by the innovator. The gap in "catch up" between the innovator and the adopter depends on the relative rates of innovation and diffusion of technology. Thus, conclude Sachs and MacArthur (2002), there are two important lessons: (i) a follower economy that adopts technology from abroad but does not innovate will always lag behind the innovator, and (ii) even technological adoption requires specialized institutions that facilitate the diffusion of new technologies.

With regard to the second lesson, Lall (2000) has claimed that "follower" strategies also require a certain degree of advanced knowledge; *"know-why"*, and not merely "know-how" capabilities. Technology import, he continues, is not a substitute for indigenous capability development; the efficacy with which imported technologies are used depends on local efforts.

Levels of analysis

Innovation systems can be defined in geographical (national, regional or global) or sectoral terms. Often, defining the system boundaries is not a clear-cut procedure. Edquist (2001) claims that if the determinants of innovations' development, diffusion and use are known, it should be possible to define the functional boundaries of the system. However, identification of the determinants, although very important, is not an easy task (*ibid.*). Van Dijk (2002), however, has suggested that the actors in innovation may be part of a network that does not have a boundary, but rather, a *focus*. Freeman (2001) has presented a detailed analysis of innovation systems on a national and regional scale.

[9] The discussion in this paragraph is based on Sachs and MacArthur (2002).

Keller and Samuels (2003) discuss the sectoral perspective. They claim that this is similar to the geographical approach in that the sectoral innovation system comprises similar relationships and institutions. However, these interact within a functionally delimited domain, which may be nationally, regionally, or globally distributed. In this view, therefore, firms in the same business - even if in different countries - have more in common with one another (and organize their R&D in the same ways) than do firms in different sectors in the same country (*ibid.*). Aerospace industries in Russia, Japan, and Indonesia - like computer industries in Korea, Taiwan, and India - have more in common with one another than do aerospace firms and computer firms in any one of these states (*ibid.*).

Whether a geographical or sectoral level is under consideration, the system can further be studied at three levels of analysis, as identified by van Dijk and Sandee (2002):

1. The macro- or policy-level, promoting (or discouraging) innovation and innovation diffusion;

2. The meso-level or the level of business support systems and how technological development and innovation are influenced at that level;

3. The level of the enterprise or a cluster of enterprises where the actual development and diffusion will take place.

Determinants of innovation within the system

Identification of the determinants of innovation has already been acknowledged as a difficult task. However, Lall (2000) suggests that the determinants reside within a framework that can be classified into incentives, factor markets, and institutions:

Incentives: these arise from the macroeconomic environment, trade policy, domestic industrial policies, and domestic demand.

Factor Markets: the most important factor markets in technology development are skills (especially technical skills), finance for technological activities, and access to information, domestic and foreign.

Institutions: here these refer to bodies that support industrial technology, such as education and training, standards, metrology, technical extension, R&D, long-term credit, technology and export information, and so on. These institutions may be government run, started by the government but run autonomously, or started and managed by industry associations or private interests.

Related to the "factor markets" category, van Dijk and Sandee (2002) introduce the "flexible specialization" concept for fostering development in small firms, in which he identifies the innovative mentality of the entrepreneur and the skill level of the workers as important factors in the competitiveness of small and medium enterprises. This view stresses the importance of factors like clusters and networks. The idea that innovation can take place more easily in networks and clusters has also been endorsed by (Steinle and Schiele, 2002).

Edquist (2001) has pointed out that sometimes the determinants of innovation systems can also be identified as being the 'specific functions' of the system, e.g., in the production of economically relevant knowledge through R&D or the financing of the development of innovations. Liu and White (2001) have also acknowledged this "lack of system-level explanatory factors" (p. 4). They have focused upon the 'activities' in the systems, which are related to "the creation, diffusion and exploitation of technological innovation within a system" (p. 6).

National Innovation Systems

A national innovation system, according to Keller and Samuels, comprises firms, universities, non-profit entities, and public agencies that produce or support the production of science and technology within national borders. This approach was originally put forward by Lundvall (1992) and Nelson (1993). Lall (2000) has put forward a similar national systems approach that examines technological activity. Although its definition[10] does not immediately set it apart from the national innovation systems approach, Lall (2000) claims that it differs somewhat from the latter in that it places more emphasis on the incentive regime, particularly trade policies. Lall's (2000) approach also introduces market failure considerations to mediate between firm- and country-level capabilities. This, he claims, provides a more coherent and systematic structure to the analysis of national systems.

One issue that has repeatedly been brought up in the literature is the relevance of national boundaries to national innovation systems. Lall (2000) claims that despite technological activities being strongly conditioned by activity in other countries,

[10] Lall (2000) defines national technological capability as "the complex of skills, experience and effort that enables a country's enterprises to efficiently buy, adapt, improve and create technologies" (p. 14).

national abilities are becoming increasingly important, particularly in developing countries. Keller and Samuels (2003) also believe that national boundaries are important. They claim that innovation systems that span sectors in the same country have more in common with each other than they do with the same industrial sector in other countries.

Edquist (2001), however, claims that if the degree of coherence or inward orientation is very low, it is not meaningful to consider the country to have a national system of innovation. Nelson and Rosenberg (1993)[11] also believe the concept may be too broad, and favor a sectoral approach towards innovation systems instead. While Carlsson and Stankiewicz (1995)[12] concede that sometimes the nation-state constitutes the natural boundary of many technological systems, they add that at other times it may make sense to talk about a regional or local technological system. Freeman (2002) also claims that many authors have argued that globalization has greatly diminished or even eliminated the importance of the nation-state. Carlsson *et al.* (2002), for instance, claim that vast improvements in communication technology in recent decades have lent an international dimension to almost any economic activity. Alternatively, some critics stress that *sub*-national entities, such as provinces, industrial districts, cities or 'Silicon Valleys' are becoming, or have already become, more important than the nation-state (in Freeman, 2002).

Lall (2000) claims that the development of capacity at the national level shares many features of learning at the enterprise level, in that countries undergo costly, uncertain, prolonged and unpredictable learning. Other characteristics of national learning he identifies are: the fact that it is path-dependent, patterns of specialization are difficult to change quickly, and the national base of capabilities determines how well countries are able to cope with new technologies. Growing national technical maturity, Lall (2000) claims, involves the industrial sector's ability to move from easy to complex technologies, and from know-how to know-why.

Freeman (2002) identifies institutional flexibility as an important aspect of national innovation systems. In his analysis of the large divergence in economic growth rates over the world in the past two centuries, he attributes these "in large measure to the presence or absence of social capability for institutional change, and especially for those types of institutional change which facilitate and stimulate a high rate of technical change, i.e., innovation systems" (p.192). Growth in British industrial districts in the eighteenth century was possible because of the presence of local institutions *and* national benefits conferred through British political, cultural,

[11] In Edquist (2001).
[12] In Edquist (2001).

economic and technological institutions (*ibid.*). Edquist (1997) claims that British economic slow-down over the twentieth century was due to the relative rigidity of organizational structures compared with informal institutions.

Since national innovation systems rely on several factors that the state must take an active role in - such as stimulating basic science as a public good, or public action that influences innovations from the demand side (Edquist, 2001), a fundamental question that arises is "what should be performed by the public sector and what should not" (*ibid.*, p. 18). Edquist justifies state intervention in two instances: firstly, if market mechanisms fail to achieve the objectives formulated, and secondly, if the state and its public agencies have the ability to solve or mitigate the problem.

The role of the institution in innovation systems

Much has already been said in preceding sections about the role that institutions can play in developing and diffusing technology. However, discussion on institutions has thus far tended to be in very broad terms. This section looks at some of the institution-specific discussion on innovation systems.

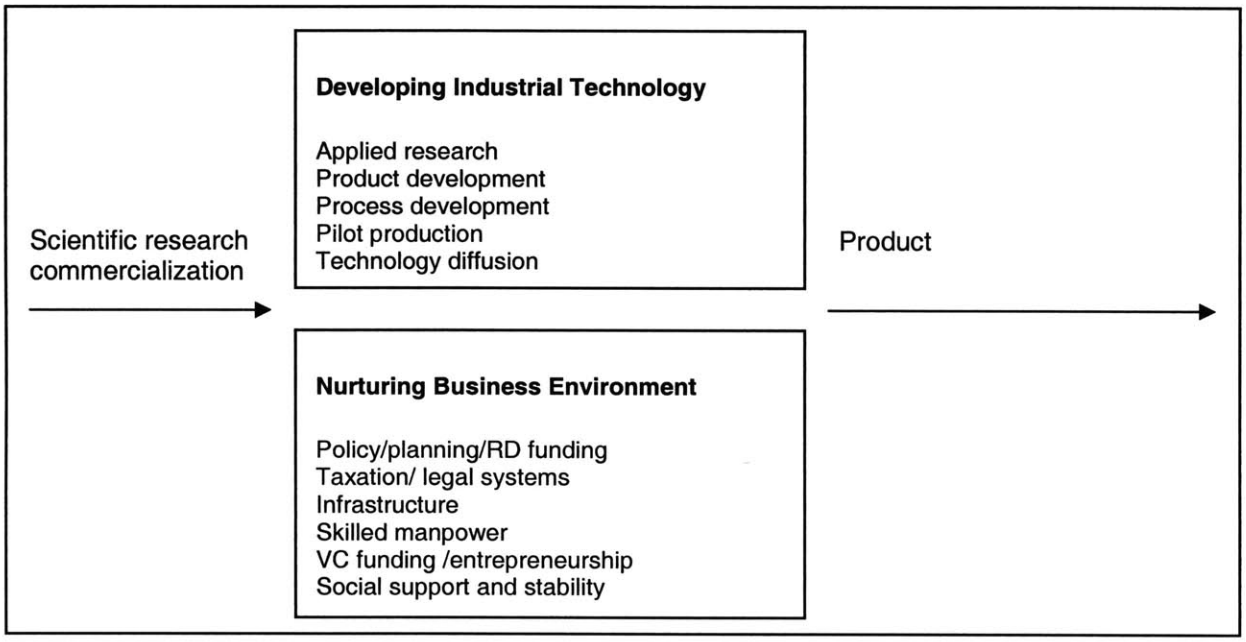
As regards definition, Edquist and Johnson (1997) have explained that 'institution' tends to hold a dual meaning in innovation literature. The first refers to 'organizations', where organizations "are formal structures with an explicit purpose and they are consciously created" (p. 47). Important instances of organizations would be companies, universities, venture capital organizations and public innovation policy agencies. Secondly, institutions may be taken to mean "sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organizations" (*ibid.*, p. 46). Examples here would be patent laws and norms influencing the relations between universities and firms (*ibid.*). Edquist (2001) claims that the relationships between organizations and institutions (norms) are important for innovation and the operation of its systems, and each may be said to be 'embedded' in the other. Some organizations directly create institutions (and institutions may also be the basis for the creation of organizations; *ibid.*). There may also be important interactions between institutions. Thus the relationships between organizations and institutions are complex, characterized by reciprocity, and may support and reinforce each other (they may also contradict and be in conflict with each other; *ibid.*).

Whitley (2002) has referred to studies that have contrasted the technological and sectoral specializations of Germany, the United States, and some other countries in the past few decades. These studies have highlighted how differences in welfare systems, employment law and conventions, the organization of business associations, training systems, financial markets, and legal systems generate different incentives for individuals and firms to pursue distinctive innovation strategies. These institutional variations, it is claimed, not only lead to different rates of innovation and technical change across industries, but also encourage different kinds of firms to concentrate on different kinds of innovations within new industries (Casper, 2000 in Whitley, 2002). The development of differing combinations of institutional features becoming established in different market economies can, Whitley (2002) claims, help explain continuing variations in patterns of technological change between countries. For a detailed discussion on the role of institutions in the biotechnology and computer industries, see Whitley (2000), particularly for his discussion on how innovating firms develop distinctive competences.

The institutional dynamic in a country may be crucial for the resilience of its economy. Keller and Samuels (2003) state: "the elements of institutional configuration of a political economy - its regulatory structure, the organization of private interests, their relationship to the state, and the location of local firms in the value-added supply chain - may each be critical in determining its capacity to resist external shocks" (p. 5). An economy that is less vulnerable is more likely to be capable of sustained growth.

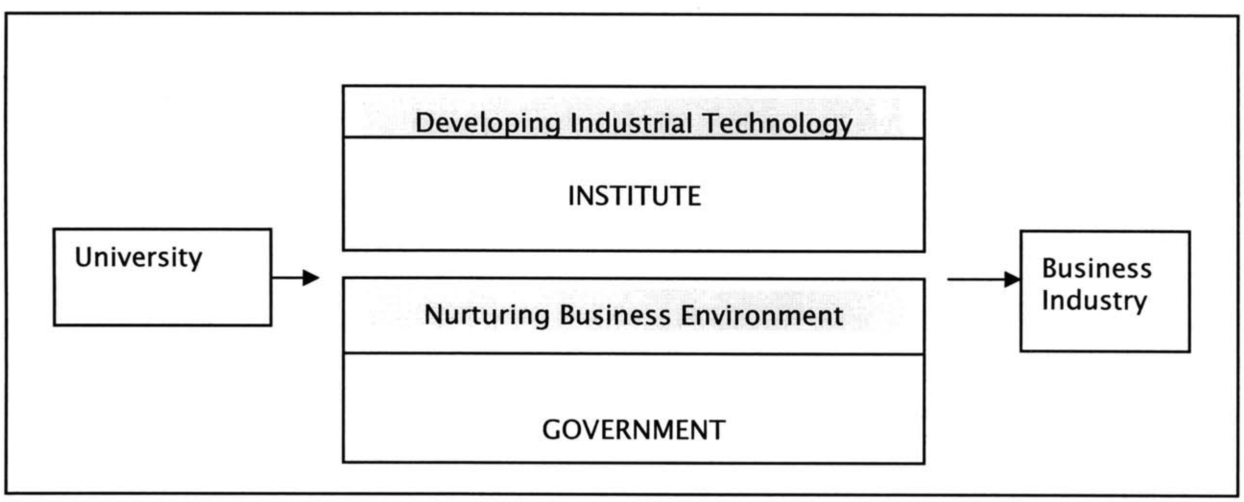
Thus far the importance of institutions within the innovation system has been discussed. It is also worthwhile to know where institutions fit into the innovation system, i.e., how do they, in general terms, link up with industry, the state and academia? Lin (2003) provides a simple model (Figs. 2.2 (a) and (b)) to show the key functions of institutions within a national innovation system. Thus the model shows that they provide the key link between academia and industry in the development of technological products. It should be noted that the services provided by the government in this model are also "institutional", but perhaps not as directly technology-related as the others.

Fig. 2.2(a) The Innovation process: Creating Wealth from Knowledge



Source: Lin, 2003

Fig. 2.2 (b) National Innovation System: The Players



Source: Lin, 2003

Innovation in Developing Countries

The need for technological development

Developments in science and technology can provide solutions to the problems facing the world's poorest developing countries (Sachs, 2002). To name just a few, these countries are facing problems in agriculture, environmental degradation, health and energy supplies. The developing world is aware that it is lagging behind, and catching up is viewed as a priority by most developing-country governments. The Group of 77 (G77), a negotiating bloc of developing countries, recently expressed "deep concern" over the prevailing and growing knowledge gap between the North and the South, and affirmed its commitment to "the promotion and development of knowledge and technology in the South"[13]. Developing countries have also consistently pushed hard for Northern countries to commit to technology transfer in international treaties and protocols.

The first reason, then, that developing countries would be interested in technology growth is to reduce the direct effects of poverty on their people. This can be done through improved medical facilities, better agricultural equipment and irrigation methods, better shelter and infrastructure, and reduction of urban pollution.

A second reason would be to boost their economies by improving industrial production. Choi (1986) claims that a three-way relationship exists between science and technology, industrial development, and economic growth of a nation: "...advances in science and technology give rise to new knowledge, new products, new processes. These innovations spawn new industries which yield economic gains and also lead the economy into new directions" (p. 2).

The third reason pertains to the need for developing countries to bridge the widening knowledge gap between themselves and developed countries. Lall (2000) claims that in today's globalizing world, it becomes even more important for developing countries to deepen their technological base. Since international competitiveness has become the prime consideration in attracting new, high value-added foreign direct investment, developing countries must offer production sites that have not just low wages, but world-class technical and managerial skills (*ibid.*). To upgrade these, and to attract new, higher value-added activities, they must provide a growing base of advanced manufacturing

---

[13] In its 'Dubai Declaration for the Promotion of Science and Technology in the South', April 2000.

and design skills and flexible and specialized supplier and support networks. Furthermore, to capture some of the externalities generated by technologically advanced MNCs, domestic firms must be able to learn from them. Further, building these capabilities will help developing countries decide which technologies will best address local needs and how they can be adapted to do so. The mere transfer of technology from the North, particularly by multinational corporations, is seen as a sub-optimal strategy that does not necessarily address local needs or help build capacity in developing countries (Buatsi, 1988).

The process of technological change

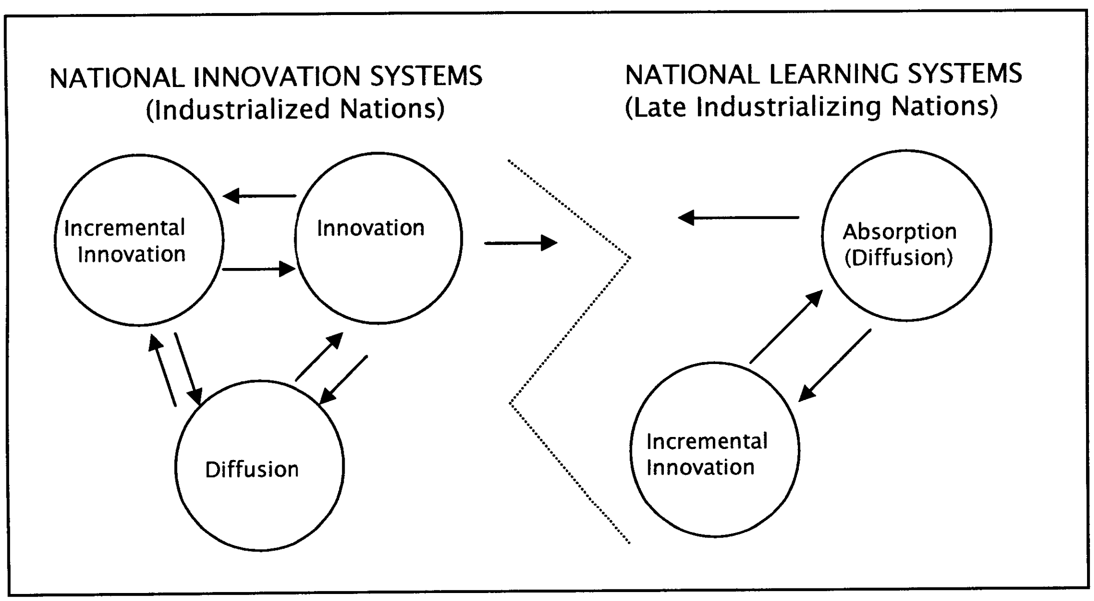
The process of technological change in developing countries is one of acquiring and improving on technological capabilities rather than of innovating on all frontiers of knowledge (Lall, 2000). Developing countries obtain their industrial technologies mainly from the industrialized world, and their main technological challenge, at least initially, is to master, adapt, and improve on the imported knowledge and equipment (*ibid.*). The need for local learning exists even if the seller of the technology provides advice and assistance. Technological learning calls for conscious, purposive, and incremental efforts – to collect new information, try things out, create new skills and operational routines, and strike new external relationships (*ibid.*)

The NIS approach and developing countries

Recently, analysts such as Cooper (1994) have posed the question of whether studies using an innovation systems approach in industrialized countries can offer insights into innovation processes in developing countries; thus far, both sets of studies have been carried out in isolation.

Viotti (2001) states that studies that have used the national innovation systems approach on industrializing economies seem to have accomplished little, and that this has not been due to lack of available data. The problem, Viotti claims, lies in the NIS approach itself; the theoretical and conceptual framework is not appropriate for dealing with the processes of technical change typical of industrializing countries, which are extremely different from those of industrialized countries. The NIS approach provides a framework for analysis of technical change at the level of national economies, and most NIS studies – whether on industrial or developing economies – have focused primarily on scientific and technological activities aimed at innovation (as admitted by Nelson (1993), of his 15-nation study). Viotti argues that this is opposed to the broader understanding of NIS, which encompasses institutions that directly and indirectly influence the innovation process. While this broader view is required to assess innovation in industrializing economies, he states, it would still be of little use if the meaning of innovation is taken to be synonymous with technical change. The problem, he identifies, is that "the process of technical change characteristic of these economies is largely shaped outside the realm of those institutions that are at the core of the innovation process" (p. 2); "innovation has a secondary role, possibly no role at all, in the process of technical change." (p. 4). Viotti has instead promulgated his theory of national *learning* systems for developing economies, with its emphasis on active and passive learning[14]. Learning, Viotti proposes, is the process of technical change achieved by *diffusion* and *incremental innovation* (see Figure 2.3 below).

Fig. 2.3 National Systems of Technical Change



Source: Viotti (2001)

Sachs and McArthur (2002) have stated that, increasingly, the goal is to understand technological innovation in developing countries as an "endogenous" feature of the economy, as opposed to something brought in from the outside.

---

[14] According to Viotti (2000), active learning is a consequence of deliberate efforts and investments in technology, while passive learning requires little or no explicit action; it is a kind of free by-product from carrying on with production.

The broad aim of such an approach is to understand how a society produces technological advance.

This view, according to Barbier and Homer-Dixon (1996), points to institutional and policy failures as the forces that prevent poor countries from generating or using new technological ideas to reap greater economic opportunities. They claim, however, that this view omits the important contribution of natural resource degradation and depletion to institutional instability. "Rather than generating automatic market and innovation responses, worsening resource scarcities in poor countries can lead to social conflicts and frictions that disrupt the institutional and policy environment necessary for successful innovation" (*ibid.*, p.1). This constraint, they believe, may help explain the disappointing growth performance of many poor countries.

What is really needed now?

Imitation is generally one of the initial stages of technological change in developing countries, and a precursor to the adaptation and local assimilation of technology. These processes were useful in helping Japan, Korea (Choi, 1986) and Taiwan develop technologically. The need to start with imitation arises partly because of the limited technical resources of developing countries, and partly because of their comparatively limited production experience (Cooper, 1994). The skills required to imitate are a subset of those required for innovation, and may eventually become a foundation for true innovation (*ibid.*). However, failure may occur in the absence of conscious allocation of resources within the firm, careful organization, or the absence of appropriate external institutional conditions (*ibid.*).

Gerschenkon (1962, 1963)[15] claimed that latecomer firms have advantages that were unavailable to the pioneering firms of a technology[16]. However, his views have since been challenged by authors who observed differently (e.g., Bell and Pavit, 1993). Perez and Soete (1988, in Freeman, 2002), in fact, revealed the *disadvantages* that latecomers must face; for instance, even imitation may be costly in the absence of an infrastructure.

---

[15] In Freeman (2002).

[16] Such as being able to acquire and use latest technology at much lower costs than those in the pioneering countries; not having to face all the uncertainties, costs and difficulties of opening up entirely new markets; and being able to move rapidly to large-scale production (*ibid.*).

STAP (1996) has noted that today the capacity to replicate is poorly developed in developing countries, and has identified some of the main reasons for this: (i) leaders there are rarely interested in nurturing the development of the capacity to innovate; (ii) even when R&D capacity exists, close involvement of industry is rare; and (iii) bilateral and multilateral assistance targets only those technologies that have a proven track record in already industrialized countries (moreover, they too provide little assistance aimed at nurturing the capacity to innovate).

What needs to be done, given the fact that engineering and management skills required for innovation are substantial, is to make training an important part of any technology transfer package, deliberately planned as a learning vehicle for the work force of the recipient firm (Imai, 1994). The transfer should not only be of specific know-how, but also of related systemic knowledge of the relevant technologies so that recipients can add value (STAP, 1996). This is an important consideration for developing countries, because it implies that the work force must experience continual cumulative learning, both from experience and formal training, in order to remain competitive in a world market where intense continual incremental improvement is increasingly essential to sustained competitiveness (Brooks, 1995). In those regions of the developing world where existing capabilities are weak in specific technology areas, basic level of technological capability should be built via the establishment of regional institutes that provide training in the fundamentals of technology assessment and management (STAP, 1996).

Research priorities need to be targeted according to domestic needs; attempting to follow the development path of the North would be "pursuing the form, rather than the substance of a successful development strategy" (Swanson, 1999: p. 29). Strategic industries need to be selected based on the country's historical background, internal and external circumstances, marketing outlook, future potential, and accumulation of science and technology at the time (Choi, 1986).

All the above recommendations have strong institutional dimensions. Appropriate organizations and policies will need to be created or re-oriented. Since, in many developing countries, there is often insufficient participation of industry in science and development (Choi, 1986), the government may be required to play a strong role. Creating institutional partnerships, both local and international, can help industries apply the knowledge domestically (*ibid.*) and thus move ahead independently with technology they require. This is crucial for real development to occur; a permanent situation of simply being "handed over" technology from the North would mean that they would never be more than "developing" countries (*ibid.*). Choi states that research institutions working independently or in partnership to help local industries implement technology must fulfill the following important roles:

- take in and ingest the latest high technologies from abroad and transfer them to domestic industries;
- improve existing technologies and create new ones;
- serve as a channel for introducing new technologies. The institute will locate well-established and appropriate technologies, and transfer them to industries where they are needed. It should maintain connections with various research institutions throughout the world to have at its disposal a wide range of information - technical, economic and cultural - and comparison of different alternatives for the appropriate choice of technologies;
- take responsibility for the education of research personnel, in order to utilize them more effectively;
- have the ability to cope with a diverse range of research problems;
- provide practical and professional experience to scientists and engineers;
- create an atmosphere which is conducive to creative innovative activities.

Sachs and McArthur (2002) agree that being "handed over technology" is not the long-term solution for developing countries. While the income gap between East Asia and the US has greatly narrowed, largely due to its formation of indigenous institutions[17] for quickly adopting technological advances from abroad (*ibid.*), it has not closed. It will close, the authors claim, only when East Asia starts to innovate in its own right.

Conclusions

While much has been written on the concepts of innovation and innovation systems, there is still lack of consensus on several important issues, ranging from the definitions of 'innovation' and 'institution' to concerns about how to identify the determinants and boundaries of the system. Whether the same national innovation system approach can be applied to both industrialized and developing economies is also an issue under debate.

It was seen that national innovation systems are highly dependent on institutions and the relationships between them to function smoothly. In the case of developing

[17] These included the creation of special economic zones, export processing zones, science parks, and other institutional arrangements to entice foreign investments in the electronics sector who were looking for low-cost places to produce their products (*ibid.*).

countries, it was noted that building capacity through institutional strengthening is a vitally important requirement.

The next chapter will build upon the theoretical background presented here, and examine Taiwan's recent technological success, with particular emphasis on how it structured various institutions and policies to bolster national technological development.

3 TAIWAN'S RISE IN HIGH-TECH INDUSTRY

Chance favors only the prepared mind.

Louis Pasteur

Introduction

This chapter takes a closer look at Taiwan, and is divided into two main parts. The first is a brief history of Taiwan's spectacular economic and technological climb in recent decades, highlighting some of the important policy decisions that helped accomplish this. The second part of the chapter looks closely at Taiwan's innovation system: how it was built up to be able to support and facilitate Taiwan's development.

Why focus on Taiwan?

In many developing countries today, a large segment of the population is illiterate, has limited access to basic resources, and is deprived of the products of global technological advance (see Table 3.1 for some development indicators in selected developing countries). A major concern is the widening gap between developing and industrialized countries. The convergent impacts of globalization, the increasing importance of knowledge as a main driver of growth, and the information and communication revolution (World Bank, 2002), are causing developing countries to feel increasingly left behind. Developing-countrypersons may well ask: is 'catch up' really possible? After all, it took most industrialized nations 150 years to get where they are today.

Taiwan's recent history can offer grounds for optimism to the developing world. In a mere forty years, Taiwan has metamorphosized from a struggling, developing country into a world leader in the production of high-technology. Often hailed as a development 'miracle', Taiwan's immense economic and technological success is generally attributed to a number of macro-economic policies and institutional reforms carried out over recent decades. These are briefly discussed in the next sections.

In the 1950s, Taiwan's socio-economic conditions were not very distinguishable from those of many other developing countries. In 1949, average per capita income was below US$100, roughly the same as India's (Hobday, 1995). Nearly 35 percent of the population over age six was illiterate in 1951 (GIO, 2003). The economy was largely agriculture-based - a hallmark of developing-country economies - and heavily supported by aid from the United States.

A mere forty years later, Taiwan has emerged as one of the world's leading producers of high-technology products. Its computer industry has grown to be the third largest exporter in the world, and its semiconductor-producing industry is the world's fourth largest (Hsu and Chiang, 2001). In 2001, the United States Patent and Trademark Office granted 6,550 patents to Taiwan, ranking it fourth in patent volume worldwide (Wu *et al.*, 2000). Taiwan's per capita GDP was $17,000 in 2001 (CIA, 2003). This wealth is remarkably evenly distributed, with the richest quintile's income roughly only 5 times that of the poorest quintile (Wu and Tseng, 1998). Over 94 percent of its population is now literate (GIO, 2003). The economy's reliance on agriculture has fallen steeply; agriculture contributed only two percent to Taiwan's exports in 2000 (*ibid.*) while industrial goods accounted for 98.6 percent (EIU, 2001). The biggest category among these was electronics products (21.4 percent in 2000; *ibid.*).

Table 3.1 Some Development Indicators for Selected Developing Countries

Country	GDP per capita (PPP US$) 2000	Adult literacy rate (% age 15 and above) 2000	Technology (diffusion and creation)				
			Telephone mainlines (per 1000 people) 2000	Internet hosts (per 1000 people) 2000	Patents granted to residents (per million people) 1999	Scientists and engineers in R&D (per million people) 1999-2000	High-Technology Exports (as % of manufactured exports) 2000*
Brazil	7,625	85.2	182	5.2	2	168	19 (59)*
Egypt	3,635	55.3	86	(.)	(.)	493	(.)[b] (37[b])*
Philippines	3,971	95.3	40	0.3	(.)	156	59 (92)*
India	2,358	57.2	32	(.)	1	158	4[b] (79[b])*
Nicaragua	2,366	66.5	31	0.3	..	203	5 (8)*
Pakistan	1,928	43.2	22	(.)	..	78	(.) (85)*
Nigeria	896	63.9	4	(.)	..	15	13[b] (.)*
Chad	871	42.6	1	(.)	..	..	.. (..)*
Ethiopia	668	39.1	4	(.)	..	..	(.) (10)*

(.) less than half the unit shown

.. data not available

( )* manufactured exports shown as percentage of exports in brackets

b data refer to 1999

Source: Adapted from UNDP, 2002

The next section takes a brief look at Taiwan's rise to high-technology industrial success over the past four decades.

TAIWAN'S ECONOMIC RISE: A BRIEF HISTORY

An Agricultural Country: the 1940s

Taiwan had a varied history of colonization since the 16th century, during which it was subjected to periods of Dutch, Spanish, Manchu and Japanese rule. Japan handed the island over to China in 1945. In 1895, when Japan acquired Taiwan, its agriculture was stagnant and its peasants were engaged almost exclusively in subsistence farming (Ho, 1968). Over the next 50 years, Japan selectively developed certain aspects of the Taiwanese economy, the main objectives of its policy being to supply the Japanese empire with agricultural products, create demand for Japanese industrial products (*ibid.*), facilitate Japanese expansion into Southeast Asia (Amsden, 2001), and provide Japan with processed goods from the raw materials Japan imported from Southeast Asia (Hobday, 1995).

Industrial diversification did not go far in Taiwan, where the manufacturing sector remained dominated by food processing, particularly sugar refining (Amsden, 2001). However, Taiwan did achieve rapid and sustained agricultural growth, despite widespread tenancy and very unequal land distribution (Myers and Ching, 1964). Ho (1968) attributes this growth to technological change; in the period 1920–1940, agriculture began to take the form of a modern, scientifically-oriented sector. Agricultural science was promoted through improved seeds and cultivation techniques (*ibid.*), which the Japanese promoted by working through the landlord and wealthy farmer classes (Myers and Ching, 1964). Ho (1968) also emphasizes the role played by modern rural institutions in making scientific farming an effective agent of growth. It was through such institutions, he claims, that the findings of agricultural science were introduced, disseminated, adopted and applied. He sums up their importance by saying (1968, p. 327): "Perhaps the lesson of Taiwanese agriculture is not that scientific farming is important, but rather that science alone cannot transform agriculture without certain rural organizations being created first or at least concomitantly."

Agriculture continued to play an important role in the Taiwanese economy until the 1970s. Land reforms in the 1950s increased farm production, and high yields permitted the export of surplus (GIO, 2003). The foreign exchange thus generated was used to purchase raw materials, machinery and equipment for the industrial sector. Eventually, traditional agriculture was replaced by high-value crops. Exports of agricultural surplus then became exports of processed agricultural goods. In 1959, 90 percent of Taiwan's exports were agriculture or food related (GIO, 2003).

The Transformation Begins: the 1950s

Over the coming decades, Taiwan was to transform itself from an agricultural country to an industrial one with a strong economic dependence on manufactured exports. The 1950s mark the beginning of this transition and are characterized by a range of measures adopted by the government to protect infant industry. A combination of factors led to the Taiwan government's decision to promote the import substitution of textiles: the inability to continue importing textiles from China, the fact that imports from Japan were eating up foreign exchange, and the presence of Chinese mainlanders with extensive textile-manufacturing experience (Amsden, 2001). These import substitution policies included stringent import measures, high tariffs, and multiple exchange rates (Wu and Tseng, 1998). The aims were to restrict the availability of foreign products in the local market and to nurture domestic enterprise. The government assisted entrepreneurs in order to boost investment, and many of these early entrepreneurs later became the founders of large business groups (Amsden, 2001). Other industries began to flourish too, such as flour-milling and machine tools (again largely due to the experience brought by the Chinese émigrés, and these, by and large, took the form of small businesses (*ibid.*)). According to Ho (1978 in Amsden, 2001), a remarkable degree of import substitution occurred in less than a decade; by 1954, imports as a percentage of supply were only 3.8 percent.

Thus, at this point, Taiwan was a suitable locale for foreign original equipment manufacturers (OEMs)[18] to source their parts and components (Amsden, 2001). At the same time, the import substitution policies were proving insufficient in boosting the Taiwanese economy due to the small size of the Taiwanese market, which limited economies of scale (Wu and Tseng, 1998). In the absence of other large markets, industries could not create new jobs (Yeh, 2001). Trade deficits were significant because of the import of equipment and raw materials for domestic industries, and expansion in the production of agricultural products was limited by

---

[18] OEM is a term that stands for Original Equipment Manufacturer. Over the years, the term manufacturer has become very loose and often means maker or assembler. It is a term to segment out a section of the industry that creates computers or computer equipment. Since 1985 the term has come to mean unnamed or unbranded. Hence, a manufacturer of unbranded products or a reseller that brands unbranded products to a proprietary brand or name.
(http://www.csgnetwork.com/glossaryo.html/#OEM), the Computer Support Group Network Online.

the slow expansion of arable land (*ibid.*). Therefore, the government decided on a drive towards export growth, of the products of both local and foreign firms.

The Move into Manufacturing: the 1960s and 1970s

Export promotion policies began to be put in place alongside the import substitution policies, and continued when Taiwan began to ease restrictions on imports and open its domestic market to foreign products. Wu and Tseng (1998)[19] discuss the three main effects of the policies. Firstly, the removal of trade restrictions and lowering of import tariffs allowed local enterprises to learn from imported products that were now entering the domestic market. This learning experience was to help Taiwan tremendously in the future. Secondly, a range of measures was adopted to actively boost exports. In order to lower production costs, imported machinery, materials, and semi-finished products were exempted from taxes if they were used to produce exported goods. The currency was depreciated. Various tax refund schemes were put in place to help reduce the cost of exports. In 1972, these tax refunds amounted to 62 percent of all tax revenue. Banks provided low-interest loans to exporters - critically important for the small and medium-sized enterprises. Close government-industry contact allowed the regular adjustment of incentives to permit the manufacturing sector to adapt to new foreign market shifts (Davies, 1981). The government made clear to investors that the priority it placed on developing exports would continue into the future (*ibid.*).

Third, the government established export-processing zones (EPZs) to attract multinational corporations to move their production bases to Taiwan (Wu and Tseng, 1998). Import and export procedures were kept as simple as possible for these firms to reduce their administrative costs, and they were allowed to import machinery and goods for reprocessing duty-free. The strategy worked very well; foreign capital poured into Taiwan to take advantage of the ample and relatively inexpensive supply of labor and the government's tax incentives. For Taiwan, this brought job opportunities and foreign exchange, but, most importantly, it brought much needed technology into the country. The technology, trained labor, and professionals spread to other parts of the country as people relocated or started their own business. Most of the foreign firms that moved into the EPZs were large multinational electronic firms, and the technologies they transferred positioned Taiwan very well for its eventual decision to develop the information industry.

---

[19] The rest of the discussion in this section is based upon the work of Wu and Tseng (1998), unless stated otherwise.

The export promotion policies helped the Taiwanese economy take off rapidly. Bass (1999) has computed that Taiwanese exports grew on average by 11% per year from 1952 to 1965, and Wu and Tseng (1998) claim that the country's gross domestic product (GDP) growth rate reached an average of 10 percent annually over the 1960s and 1970s. The export-oriented policies, in exposing domestic enterprises to the competitive world market early on, taught them how to produce goods as simply and cheaply as possible. Market forces guided local enterprises to concentrate in sectors which Taiwan had a comparative advantage in at that time: textiles, clothing, shoes, toys and consumer electronics (*ibid.*). Most of these required highly labor-intensive technology. Table 3.2 shows Taiwan's progress over this period relative to other developing countries.

Table 3.2 Average rate of Growth of GDP for Taiwan, Other Developing Countries, and Developed Countries (Percent)

	Taiwan	East and Southeast Asia (excl. Japan)	Developing countries	Developed countries
1950-1960				
Real GDP at factor cost	**7.4**	4.0	4.6	3.7
Per capita GDP at factor cost	**3.8**	1.8	2.4	2.4
1960-1971				
Real GDP	**10.1**	4.7	5.3	5.0
Per capita GDP	**7.3**	2.3	2.7	3.9

Source: Ho (1978)

Between 1949 and 1973, manufacturing production increased at an average rate of 17.6 percent per year (Ho, 1978) and came to be the mainstay of the Taiwan economy by the early 1970s. In 1973, it contributed 31 percent of Taiwan's GDP (in current prices) at factor cost, accounted for over 90 percent of the exports, and employed more than one quarter of the labor force (*ibid.*).

The 1970s onwards

(i) Machinery

Labor costs began to rise in the 1970s, and producing labor-intensive goods became costly (Wu and Tseng, 1998). Consequently, Taiwan began to lose its comparative advantage in producing labor-intensive exports (Timmer, 2000). The situation was further compounded by the energy crisis, which profoundly affected the world economy (Li, 1995), and caused energy and wage costs to rise in Taiwan

(Davies, 1981). Taiwan began to experience a tightening of trade barriers in developed countries and also to realize that it would face increasing competition in the production of labor-intensive goods from China and Southeast Asia (*ibid.*).

Accordingly, the economy began to adjust itself towards the production of products that were more capital and technology-intensive. Exports moved away from the canned vegetables, clothing, plywood and cotton fabric of the early 1970s towards synthetic fibers and office machinery by the mid-1980s (Riedel, 1992 in: Timmer, 2000). According to Timmer (2000), a secondary phase of import substitution began as industrial output gradually moved towards metal and machinery manufacturing, in order to provide the domestic market with intermediate goods. The move to machinery proved very successful; Taiwan eventually became the world's fifth-largest machinery exporter (Chang *et al.,* 2002), primarily due to the industry's remarkable versatility. From numerical controls (NC) in 1955, the industry first moved to computer numerical controls (CNC) in 1965, then to flexible manufacturing systems (FMS) in 1975, and eventually computer-integrated manufacturing (CIM) combined with factory automation in 1985, thus completely overhauling the machinery industry (*ibid.*).

Thus the government's response to the loss in comparative advantage in labor-intensive goods was to promote 'strategic', high-technology industries (Timmer, 2000). The long-term aim was to create a science and technology infrastructure to support the technological efforts of private firms. Government policies to promote science and technology are discussed later in this chapter.

(ii) Electronics

The development of the electronics industry in Taiwan initially relied on a multitude of small and medium-sized enterprises (SMEs), and benefited considerably from transnational corporation (TNC) investments, joint ventures and foreign buyers (Hobday, 1995). Taiwan's first mature, mid-technology export was the television, where production was dominated by foreign-owned firms such as RCA (Amsden and Chu, 2003). TNCs helped to foster the start-up of many of Taiwan's electronics makers as large numbers of local firms supplied them with goods and services, leading to a thriving subcontracting and OEM system. Under OEM, local firms made products based on designs and plans provided by foreign companies. The finished goods were then marketed and sold using the brand names of the foreign firms. Large-scale production of monitors and terminals was initiated in Taiwan in 1980 by foreign subsidiaries, and national firms quickly increased their production and exports. By 1983, a mere three years after start-up, nationally-owned firms accounted for more than 63 percent of output and 60 percent of exports of monitors, and 51 percent of output and 52 percent of exports of terminals (Amsden and Chu, 2003). Calculators, too, began to be mass-assembled in the 1970s, based almost entirely on imported components. Alongside television, they provided a laboratory for learning mass production techniques, managerial as well as technological (*ibid.*).

While OEM continues to be important in Taiwan, local firms increasingly provided more comprehensive services for foreign firms procuring goods from Taiwan (EIU, 2001) and by 1989 the term 'original design manufacture' (ODM) was widely in use. Latecomers learned to design and manufacture products then to be sold under a foreign buyer's brand name. ODM provided an alternative to 'own-brand manufacture' (OBM) for small firms and, importantly, it signified a new stage in latecomer product innovation, going beyond processes learned under OEM and subcontracting (*ibid.*). Under both ODM and OEM, exports focused domestic learning efforts and helped to pull Taiwan's competitive capabilities forward. Some firms, notably the personal computer maker Acer, have also begun OBM, developing their own internationally recognized brands (EIU, 2001).

Taiwan's electrical appliance industry relied heavily on foreign investment. In 1975, foreign firms accounted for over 80 percent of the electronics industry's exports (Amsden and Chu, 2003). As the skills of national investors improved relative to those of foreign investors, however, the involvement of the latter weakened. By 1998, they accounted for less than 8 percent (*ibid.*, see Table 3.3, below).

Table 3.3 Share of foreign-owned firms in exports, by industry, 1975-1998 (%)

	1975	1985	1991	1995	1998
Food	1.5	2.6	9.3	2.4	7.1
Textiles	25.9	7.3	3.0	6.9	3.7
Minerals	13.3	3.7	8.9	26.3	9.0
Metals	10.7	5.1	5.6	4.6	1.5
Machinery	22.7	13.6	7.8	12.1	10.0
Electronics	**81.9**	**35.7**	**18.4**	**8.1**	**7.9**
Other	9.1	3.5	5.4	10.0	5.1
Total industry	19.7	10.4	8.5	7.8	7.7

Source: Adapted from Taiwan, Ministry of Economic Affairs, in: Amsden and Chu (2003)

The output of Taiwan's electronic and information industry grew by an average of almost 15 percent per year during 1996-2000 EIU (2001). Taiwan moved very successfully into the production and design of a range of high-technology electronic products and components. By 1999, roughly 80 percent of the output value of its information technology industry was accounted for by production of laptop computers, monitors, desktop PCs, and motherboards (*ibid.*), and Taiwan is now the world's leading manufacturer in about a dozen categories of computer-related products (see details on some of these in Table 3.4). Taiwan's computer industry has grown to be the third-largest exporter in the world for some years now, surpassed only by USA and Japan, and its production of semiconductors is fourth-largest worldwide (Hsu and Chiang, 2001).

Table 3.4 Taiwan's Global Market Share in Computer-Related Products (2000)

Product	Taiwan's global market share (2000) (%)
Motherboards	70
Scanners	92.5
Computer cases	77
Power supplies	74
Notebook PCs	50
Desktop PCs	21

Source: EIU (2001)

Other considerations

Davies (1981) highlights domestic order and political stability as important factors in the government's ability to play a strong and successful role in Taiwan's development. Yeh (2001) also credits Taiwan's economic growth to its abundant supply of diligent labor with a strong willingness to learn. Starting the late 1950s, the Taiwan government has followed a long-term strategy of improving education and literacy by measures such as extending the duration for compulsory education, and strongly encouraging vocational education (Yeh, 2001).

Taiwan received ample amounts of aid from the US until 1965. This was US$100 million annually, which, in certain periods, greatly helped offset trade deficits and facilitated the import of daily necessities, capital equipment, and raw materials (Yeh, 2001). Yeh (2001), and Chan and Clark (1992) claim that this aid was not the key factor in Taiwan's economic growth, however, since after 1965, when the aid was discontinued, Taiwan did not suffer any setbacks in growth or investments. Aware that the US aid was meant to be temporary, Taiwan had long planned on various self-help measures (Yeh, 2001). Myint (1982) also claims that the importance of the US aid factor is debatable, stating that during Taiwan's spectacular growth phase during the 1963-73 period, it managed to do with very little net inflow of foreign savings.

Taiwan's rapid technological advances were made possible by its carefully engineered systems to induce innovation. These included both the creation of public institutions that worked with the private sector, and appropriate policies to help them function as planned. The remainder of the chapter describes some of the key policies and institutions.

INNOVATION IN TAIWAN

Taiwan owes much of its success to the ability of its firms to continually adapt, upgrade, and assimilate new technologies. Creating an environment to facilitate these processes has been a major priority for the government of Taiwan (Tsai and Wang, 2002), and putting in place the institutional framework to facilitate innovation has been a vitally important achievement. The framework includes the creation of science parks and public R&D institutes (Amsden and Chu, 2003), and was supported by fiscal policies (*ibid.*) and periodically updated S&T plans (Li, 1995).

There are various reasons why the government deemed it necessary to assert itself strongly in setting up the institutional environment for innovation. According to Tsai and Wang (2002), Taiwanese firms were reluctant to invest in innovation. This was due to (i) the fact that most of them were SMEs with limited resources and R&D capabilities, (ii) the uncertainties and risks of R&D within high-tech industries, and (iii) barriers associated with minimum scale (*ibid.*). Hsu and Chiang (2001) claim that Taiwan was also relatively disadvantaged because of its shorter industrial history, weaker technical capability, and scattered technology development investment. It was therefore imperative for the government to design a technology strategy to develop high-tech industries.

Key institutional and policy vehicles that drove Taiwan's industrial upgrading process are discussed below.

POLICIES AND INSTITUTIONS

Laying out National Goals and Plans

As early as 1959, the government of Taiwan laid out the guidelines for 'National Long-Term Science and Technology Development'. A task force was established to oversee the progress of the plan; its objectives were: planning and promoting long term scientific research; reviewing R&D budget allocation; recruiting and involving professors; and sponsoring S&T personnel to go abroad for advanced studies (Li, 1995). In 1967, the National Long-Term S&T Development Committee was reorganized into the National Science Council (NSC), which was instructed in 1969 by the government to formulate a 'National Science Development Plan (1969-80)' (*ibid.*). The Plan's overall goals were (i) to coordinate S&T and economic development, and (ii) to stress applied technology research (Li, 1995). Specifically, it made the following recommendations for science and development (*ibid.*):

i) strengthen basic education by upgrading curricula, faculty and facilities at elementary, junior and senior high schools;
ii) improve the research environment at universities and research institutes in order to produce manpower in high-tech;
iii) enhance R&D in the fields of industry, agriculture, transportation, medicine and public health.

Li (1995) also highlights the role of National Conferences on Science and Technology in laying out the path of future science and technology developments. These Conferences had participation from academia, industry and government. In the first Conference, held in 1978, the establishment of Hsinchu Science Park was decided upon (discussed below), to accommodate the initiation of high-tech industries. It was at this Conference that, for the first time, S&T policy was coordinated with industrial development. At the second Conference in 1982, alongside decisions to increase national research expenditure and further basic research, new strategic research areas were identified: biotechnology, opto-electronics, food processing technology, and hepatitis control. Successive conferences built upon the goals of the previous ones; the third Conference, held in 1986, for instance, had as its goals the following: broadening the R&D base; raising the quantity and quality of researchers; enhancing R&D efficiency, expanding Hsinchu Science Park, helping the Industrial Technology Research Institute (ITRI, discussed below) develop high-tech products and technical know-how; introducing more high-tech firms to Taiwan, promoting international S&T cooperation and strengthening technology transfer; and broadening public awareness in S&T.

Establishment of Science Centers

In the 1960s, the Taiwan government took concrete steps to promote scientific research to help spur industrialization. It set up five science centers (Li, 1995): mathematics and chemistry centers at National Taiwan University, the physics center at National Tsing Hwa University, the biology center at the Institute of Botany in the Academia Sinica, and the engineering science center at the National Cheng Kung University. Universities were encouraged to set up research institutes that would offer Masters degrees. These steps contributed greatly to the growth of S&T manpower, and the upgrading of R&D capability (*ibid.*).

Industrial Technology Research Institute (ITRI)

The Industrial Technology Research Institute (ITRI) was established by the Ministry of Economic Affairs (MOEA) in 1973 to provide technological support for Taiwan's industrial development (ITRI, 2003). Initially created out of a telecommunications laboratory in the Ministry of Communications (Meaney, 1994) by combining three existing institutes, today ITRI has seven laboratories, five research centers and over 6000 personnel (ITRI, 2003). Its "open lab", an incubation facility for new firms, has proven immensely successful in helping to provide them a firm footing.

ITRI has been referred to as "the powerhouse" behind Taiwan's entry into information products, semiconductors and other advanced technologies (Matthews, 1999), and as the most dynamic institution in Taiwan's national innovation system. It works closely with Taiwan's private sector, conducting pre-competitive research on projects sponsored by MOEA with a view to transferring the outcomes to the private sector non-exclusively (*ibid.*). It also conducts short and medium-term research sponsored by private firms.

A major role of ITRI is to serve as a "global technology scanner and filter" (Matthews, 1999), keeping abreast of technological developments worldwide and developing know-how in those technologies within its own labs. The aim is to spin these across Taiwan's private sector as rapidly as possible through short-lived R&D alliances with small and medium-sized Taiwanese manufacturing firms (*ibid.*). In this way, Matthews (1999) states, ITRI is able to sign technology licensing deals with the world's leading multinationals, and ensure that Taiwan's manufacturing firms gain access to these licenses and produce state of the art products for export. In some cases, they have been able to achieve this even before the originating multinationals (*ibid.*). The rapid diffusion of advanced technologies from abroad to Taiwan's firms, therefore, is attributable to ITRI (Matthews, 2001).

Matthews (2001) identifies the public-private sector cooperation witnessed through ITRI as a characteristic feature of the country's technological upgrading strategies. The movement of personnel from ITRI to the private sector helped boost the latter's

R&D capabilities and speeded up the process of technology diffusion (Tsai and Wang, 2002). A very high proportion of the staff of UMC and TSMC, of Taiwan's semiconductor industry, had previously been employed at ITRI (*ibid.*). In fact, ITRI was responsible for the creation of these leading IC firms (Amsden and Chu, 2003).

Thus ITRI's programs are designed both to facilitate the creation of new industries (such as semiconductors, chemicals, opto-electronics and aerospace), and to upgrade existing industries (Matthews, 1999). It also actively initiated projects to explore areas in which it felt the private sector could profitably invest next (Amsden and Chum 2003). Additionally, after an industry started up, ITRI would undertake smaller-scale projects to import-substitute key components, thereby furthering the government's objective to always "create local growth opportunities and local value added, besides upgrading the level of technology" (Amsden and Chu, 2003, p. 102).

ITRI, being a large organization, comprises several smaller organizations with specific functions. For instance, the Electronic Research Service Organization (ERSO) was set up to develop the IC project (Meaney, 1994). More will be said about ITRI's organizational structure in the next chapter.

ITRI also formed key R&D alliances with SMEs. These alliances were an integral part of Taiwan's industrial upgrading system. They are discussed in more detail in a section below.

Science Parks

The creation of science parks constituted a major form of government support. One was constructed in Hsinchu, south of Taipei, and another in southern Taiwan in Tainan. The Hsinchu Science-based Industrial Park (HSIP) was established in 1980, with the view of being a base for high-tech industries and the creation of a high-quality environment for R&D (Tsai and Wang, 2002). The government picked which firms would reside in these parks (Amsden and Chu, 2003) - seeking high-technology industries of the future, and provided them with attractive benefits. Firms residing in the park received a set of subsidies that included tax and import duty exemptions, grants and subsidized credit, the provision of below-market rents in high-quality factory buildings or sites, living amenities for high-caliber researchers, and access to government and university research facilities (*ibid.*). The Park also offered low-interest government loans; R&D matching funds; government purchase of technology abroad for transfer to participating companies; and government equity investment of up to 49 percent of enterprise capitalization

(Matthews, 1999). Modeled on the success of the Stanford Research Park in California's Silicon Valley, the HSIP also offers as inducements ease of access, clean environment, good housing and educational facilities, and land made available by the government (*ibid.*).

Hsinchu Science Park has played an important role in the development of the following industries in Taiwan: integrated circuits (IC), computers and peripherals (C&P), telecommunications, opto-electronics, precision machinery (PM), and biotechnology (Lee and Yang, 2000). According to Liu (1989, p. 35 in Amsden and Chu, 2003, p. 110), "The engine of economic growth in the 1980s in Taiwan [was] the information industry, while the Science-based Industrial Park [was] the driver of the engine." All Taiwan's semiconductor companies, states Matthews (1999) have their fabrication and design facilities at HSIP, clustered around the facilities of TSMC, the research and design facilities of ITRI/ERSO, and the leading national technical universities of Chiaotung and Tsinghua. Many of Taiwan's leading IT firms, e.g., Acer Inc, Acer Peripherals and Logitech also have research facilities at the Park (*ibid.*).

The success of the HSIP led to plans for its expansion (Lee and Yang, 2000) and also to the NSC's decision to create a second science-based industry park, in Tainan. The Tainan Science Park (TSP) was established in 1998 and 28 factories started their construction there within the same year (*ibid.*). The four major industrial sectors accommodated at the TSP are: microelectronics and ICs, precision machinery, biotechnology, and agriculture (Matthews, 1999).

Since 1980, the Taiwan government invested more than US$583 million in software and hardware facilities in HSIP (Lee and Yang, 2000) and by the end of 1998, the HSIP housed 272 companies with combined annual sales of more than US$13 billion (*ibid.*). According to Amsden and Chu (2003), Hsinchu Science Park accounted for a large share of Taiwan's total R&D spending - as much as 19 percent in 1998. Investments in TSP, according to Matthews (1999), are likely to be around US$2.9 billion. These are being channeled from the Hsinchu Park's operating fund and from loans raised using existing assets, rather than through fresh government appropriations.

Li (1995) identifies the following impacts of HSIP on hi-tech industries in Taiwan:

- *encouraging venture capitals into hi-tech industry*: since high risk and high returns are two characteristics of hi-tech industries, the government needed to encourage traditional enterprises to invest in venture capital companies and introduce high technology from. HSIP helped towards this end.

- *disseminating technology to accelerate the upgrading of industries*: many components needed for production in the Park were supplied by small and medium sized enterprises outside the Park. To ensure the quality of the components, the Park's high-tech companies assisted their suppliers in technical education and personnel training. This helped upgrade the technology of many satellite companies.
- *attracting overseas Chinese S&T manpower to start up business in Taiwan*: the favorable working and living environment in the Park induced many overseas Chinese S&T personnel to return to Taiwan to invest in the Park. Over half the companies in the Park at present were founded by overseas Chinese scholars and engineers who brought back specialized production technology.

According to Amsden and Chu (2003), the conditions for admission into HSIP (in 1980) were as follows:

1. A firm had to have the ability to design products for manufacturing according to a business plan.
2. It had to have produced products that had undergone initial R&D that was still in progress.
3. It had to have manufactured products with a potential for development and innovation.
4. It had to have engaged in high-level innovation and R&D in a research department that conformed with a minimum specified size.
5. It had to have adopted production processes that required the introduction of training in advanced technology, or the spending of fairly large sums on R&D.
6. It was required to employ a staff within three years after marketing a product or service comprising no less than 50 percent of local technical personnel.
7. Its operations had to contribute significantly to Taiwanese economic reconstruction and national defense.

National Laboratories

To promote large-scale research, the NSC has been coordinating with agencies and research institutes since the mid-1980s to plan the establishment of national laboratories (Li, 1995). In addition to the research facilities that NSC helped provide at universities, research institutes, and the Science Parks, five additional laboratories went under construction (*ibid.*): (i) Synchrotron Radiation Research Center (SRRC), (ii) Laboratory Animal Breeding and Research Center, (iii) Nanodevice Laboratory, (iv) Seismic Engineering Research Center, and (v) Center for High-Performance

Computing. Other laboratories being planned include the National Space Laboratory and the High-temperature Superconductor Laboratory (*ibid.*). These labs will contribute to high-tech academic research in Taiwan.

R&D Alliances

ITRI forged alliances with the private sector, particularly SMEs, which became sophisticated devices for the rapid dissemination of new technological capabilities through Taiwanese industry (Matthews, 1999). Alliances were formed in the areas of notebook computers, high-definition television, fax and communications equipment, etc. (Tsai and Wang, 2002). These alliances led to a process where R&D costs could be shared, and risks reduced, by bringing several small firms into a collaborative alliance with each other and with ITRI (Matthews, 2001), with ITRI serving as the anchor for the alliance.

The main goal of the alliances, according to Matthews (2001), is *rapid adoption* of new technological standards products or processes developed elsewhere, and their *rapid diffusion* to as many firms as possible. Early on, the initiative for the formation of alliances came exclusively from public agencies (largely ITRI or MOEA), but the private sector has been taking an increasingly active role as the institutional form of the consortia has evolved, to the point where private firms were taking the initiative in forming alliances by the end of the 1990s (*ibid.*).

These alliances have accelerated technological catch-up and learning, and resulted in a series of successful industry interventions. Taiwan's current dominance of laptop PCs for example, is partly due to a public-private sector led consortium that rushed a product to world markets in 1991 (Matthews, 2001). Similarly, Taiwan's strong performance in data switches, which are used in PC networks, rests on a consortium that worked with ITRI to produce a switch to match the Ethernet standard, in 1992-93 (*ibid.*). Also, Taiwan's emerging success in the automotive industry, driven by its development of a 1.21 four-valve engine, was again the product of a collaborative research endeavor involving three companies that have now jointly created the Taiwan Engine Company to produce the product (*ibid.*). Thus Taiwan used R&D consortia as an effective organizational form of promoting catch-up industry and technological upgrading.

Government-Led Networking

The Taiwan government took certain regulatory steps that favored the development of nationally-owned firms (Amsden and Chu, 2003). It imposed a variety of stringent restrictions on foreign entry, particularly in the early phases of a service industry's modernization (*ibid.*). Foreign participation in one of Taiwan's cell-phone service companies was limited to 20 percent through 2000; foreign banks could engage in some types of business but were not allowed to accept local deposits until 1990; foreign builders of Taiwan's high-speed rail were required by the Taiwan government to include national firms as joint venture partners or collaborators (*ibid.*). Foreign real estate companies could not speculate inland and foreigners in general faced other restrictions on land ownership. Later, restrictions on foreign investment in services were selectively removed under pressure from the United States and Taiwan's need to comply with WTO law in order to become a WTO member (*ibid*). However, government restrictions on foreign investment in services in the early stages of market-opening allowed nationally controlled firms to capture second mover advantage (*ibid.*).

Innovation Incubators

The Small and Medium Enterprise Association (SMEA) at the MOEA has promoted the establishment of incubators since 1996. While ITRI's are perhaps most renowned, incubation facilities are also being set up elsewhere. By 2002, the SMEA had promoted 63 incubators and attracted around 900 firms to move into them (Tsai and Wang, 2002).

The aims of innovation incubators for SMEs in Taiwan are threefold, according to Tsai and Wang (2002). Firstly, they promote the innovative ability of SMEs. Secondly, they serve as a bridge between the industrial sector and academic institutions, helping to transfer academic research results to industry. And thirdly, they play the role of regional innovation centers and tend to promote the competitiveness of local industry.

Industry Associations

Industry associations have played a significant role as intermediaries between state agencies and firms in Taiwan (Matthews, 1999). Major industries - IT, semiconductors, and automotive, have industry associations that help drive industrial upgrading by acting as an interface between firms and government agencies. Matthews (1999) states that the relationship between government agencies and industries in Taiwan is one of 'governed interdependence', a productive and complementary relationship in which each side provides a necessary complement to the other. Government agencies require the private sector for implementation of their policies, while the private sector needs public agencies for the coordination of catch-up activities, particularly in financial allocation, risk sharing and technological upgrading (*ibid.*).

Relations between the public and private sector are not fixed, but tend to evolve. Thus the firms and public agencies co-evolve, each adapting to changes in the others, thus stimulating a mutually dependent process of change and development (*ibid.*). Matthews (1999) states that the Taiwan government's strategies for the creation of industry have been explicit, with its agencies such as the ITRI insistent that firms must learn to survive and prosper in a world of fierce competition.

Government assistance to the industry - the nurturing of enterprises while in a fledgling state - did not expand to encompass trade protection or the rescue of enterprises facing operational difficulties (*ibid.*). Thus, the history of the creation of the industry in Taiwan is littered with bankruptcies, e.g., that of Quasel in the mid-1980s - where government refused to intervene to rescue the company in distress (*ibid.*). This would have defeated the goal of public policy, which was to ensure that firms become independent and internationally competitive (*ibid.*).

Recovery of Public Investment

Taiwan has developed an innovative approach to assessing the value of public investment in industry creation and upgrading (Matthews, 1999). Rather than requiring investments to be immediately 'cost effective', the government looks to the long term, for a return in taxes paid by successfully launched companies (*ibid.*). This approach, Matthews (1999) states, rests on the twin propositions that private R&D expenditure will eventually exceed public R&D expenditure; and company tax revenues will eventually exceed public funds paid out as R&D support.

Tax Incentives

Tax incentives offered by the government to the private sector were important in reducing the level of risk manufacturers were required to absorb when undertaking R&D and personnel cultivation (Tsai and Wang, 2002). The Statute for Industrial Upgrading and Promotion was promulgated on 1 Jan 1999, with goal of using tax incentives to encourage companies to undertake R&D, automation, personnel training and other activities (*ibid.*). Also, investment tax credits were offered to investors holding shares in companies in high-tech industries, and a five-year tax exemption was made available to companies within these industries as well as venture capital companies (*ibid.*). The Statute achieved good results in terms of stimulating expenditure, the impact on the economy as a whole, and the contribution made to industrial upgrading.

Venture Capital

A non-government factor in the development of SMEs was venture capitalists, who tend to invest in emerging industries with strong development potential on the basis of expert knowledge available to them. Venture capital funds provide capital as well as management assistance. Since the object of venture capital investment is usually an individual or an SME, venture capital in Taiwan has made a substantial contribution to the growth of SMEs, particularly those in emerging industries (Tsai and Wang, 2002).

Taiwan's first venture capital company was established in 1984 (*ibid*). Although its growth rate was slow initially, 199 venture capital companies were set up by the end of 2001 (*ibid.*). The annual growth rate in the number of venture capital companies and the amount of venture capital investment exceeded 50 percent in 1997 and 1998 (*ibid.*). Such growth has also speeded up the development of the high-tech sector.

International Linkages

The links of Taiwan's industry and academia to Taiwanese- and Chinese-American engineers and scientists in the US have played a remarkably important role in the country's development. These entities have contributed in terms of research advice, joint research and facilitation of technology transfer, as well as by returning to Taiwan to do research. Research links with foreign industry and research institutes have also been - and continue to be - very important.

Conclusions

Taiwan has achieved economic success in a remarkably short period of time. This is largely attributable to the successful development of high-tech industry in the country. The government has played a key role in promoting scientific learning and technological innovation, through the establishment of certain institutions and the formulation of sound policy.

The next chapter examines in detail one of the most important institutions created for technological learning and upgrading in Taiwan, the Industrial Technology Research Institute (ITRI). This thesis espouses the belief that Taiwan's largely SME-based industry would not have been able to achieve the degree of success that it has in the absence of such a large, government-supported research and technology implementation institute. The next chapter looks at ITRI's functions, its organizational structure, and institutional set-up.

4 ITRI: AN OVERVIEW

Chapter 3 looked at Taiwan's rapid climb to global high-tech leader. This chapter examines the vital role ITRI played in bringing this about. It will show how ITRI has been largely responsible for Taiwan's economic and technological success, starting as early as the late 1970s when Taiwan decided to move into semiconductor technology. It also builds on the overview of Taiwan's innovation system presented in Chapter 3, in showing how ITRI fits into this system.

The chapter is divided into three sections. The first section looks at ITRI's goals and history: which factors led to its establishment; which early influences helped mould it; what kind of politics were involved; and how it expanded into its current dimensions. Given the national focus at the time, the emergence of semiconductor technology is a main theme. The second section presents an overview of ITRI - its labs and centers, core research areas, and notable contributions to Taiwanese development. Lastly, this chapter examines ITRI within the wider institutional framework of Taiwan to answer questions such as: how does it fit in with other research institutes and universities; how pivotal a role does ITRI play within Taiwan's innovation system; and what are ITRI's prospects for the future?

HISTORY AND EVOLUTION

Mission

Since its establishment 1973, ITRI's vision has been "to become an outstanding research institute that uses technological innovation to assist Taiwan's industry in fulfilling the challenge of a knowledge-based economy"[20]. Its goal is to address both Taiwan's current industrial needs and its future growth. It does the latter by anticipating the marketplace and thus staying ahead of the innovation curve of

[20] This and the following information are taken from ITRI's online brochure, available at http://www.itri.org.tw/eng/about/download/intro_eng.pdf

modern industry. Such long-range development is mostly government-funded, while contract and project work from industry tends to focus on current developments[21].

Regarding Taiwan's current industrial needs, ITRI's main objectives are to:

- engage in applied research and technical services to accelerate the industrial development of Taiwan.
- develop key, compatible, forward-looking technologies to meet industrial needs and strengthen industrial competitiveness.
- disseminate research results to the industrial sector in a timely and appropriate manner, in accordance with the principles of fairness and openness.
- foster the technology development of small and medium-sized businesses, and cultivating industrial technology human resources for the benefit of the nation.

ITRI's efforts focus both on upgrading existing industry and promoting new, high-technology industry.

The Early Days [22]

In the early 1970s, the Taiwan government realized that a labor-intensive industry would not take the economy very far, and began to plan what the new focus should be (Wu and Tseng, 1998). After much deliberation, the electronics industry was chosen. As discussed below, ITRI was created to help achieve this goal. Its efforts had tremendous impact, working as it did in close cooperation with other state institutes, national committees, universities and industry - both domestic and foreign.

Establishment of ITRI

In 1974, Y.K. Sun, a former Premier of Taiwan and an electrical engineer by training, invited Dr Pan from the US to Taiwan to obtain suggestions on ways in which Taiwan could upgrade local industry with electronics playing the lead role. Pan, in a meeting with top officials that included the Premier, recommended that (i) the electronics industry focus on semiconductor technology and the technology be acquired from abroad; (ii) a two-part strategic planning team be formed, one in the United States and one in Taiwan; and (iii) an organizational capability for implementation within

---

[21] This is according to a page on ITRI's website, http://www.itri.org.tw/eng/about/index.jsp

[22] The discussion presented here on the early days of ITRI is based on Constance Meaney's (1994) narrative, unless otherwise stated.

Taiwan be set up. Also, they decided to locate a US partner that could provide technology transfer and training. Thus began Taiwan's new long-term project: the manufacture of integrated circuits (ICs)[23].

To create organizational capacity in electronics R&D within Taiwan, Sun established ITRI in 1973-74. Although the original plan was to locate it in the Ministry of Communications, Sun wanted a high degree of autonomy for the Institute and, despite opposition, had it placed under the Ministry of Economic Affairs (MOEA), which he at the time headed, although it was located in an existing communications laboratory. It is important that ITRI was actually formed by the merging of three existing research institutes: Union Industry, Union Mining Industry and Metal Industry (Li, 1995). Within ITRI, the Electronics Research Service Organization (ERSO) was set up to develop the IC project.

Originally, both ITRI and ERSO were funded entirely by the state. However, as companies began to pay fees to have products developed for them, private-sector contributions rose. By 1988, ERSO and ITRI received about 25 percent and 55 percent respectively from the government. Today government and industry provide roughly 50 percent each to ITRI. ITRI's budget is screened within the MOEA and approved by the Executive Yuan (Cabinet), the Legislative Yuan, the National Science Council (NSC), and the Science and Technology Advisory Group (STAG).

TAC Input to ITRI

Believing that it was important to have a strategic planning group based in the United States, Dr Pan invited engineers from Bell labs, IBM and various universities to form a Technical Advisory Committee (TAC). TAC's tasks were to help in selecting a particular IC technology to concentrate on, and to recommend a list of US companies that could be invited to submit bids for a technology-transfer agreement. Since its inception, TAC has regularly provided ITRI/ERSO information on industry trends and on the experience of US laboratories with different approaches to product development. TAC also submits proposals for the next major thrust of Taiwan's IC program.

Links with RCA

Human capacity-building in Taiwan's new project benefited greatly from early ties with RCA which, in late 1975, was chosen out of eight companies that had submitted

---

23 An electronic circuit where all the elements of the circuit are integrated together on single semiconductor substrate. (http://icknowledge.com/glossary/i.html)

bids. The two main points of Taiwan's strategy were (a) to emphasize training as well as technology-transfer, and (b) to solicit private investment and move technology into the private sector. RCA agreed to provide technicians plus technical training in the United States over the next five years, as well as design and production capabilities. In addition, it agreed to transfer all technological advances and improvements in design and processing, as well as provide information on product applications. In return, ITRI would purchase a certain quantity of wafers[24].

Dr Pan recommended that forty young engineers be sent to RCA for training in relevant fields (processing, design, testing, plant engineering, accounting and reliability studies) who, upon their return, would take up positions within ERSO. The same year, 1976, construction began on an IC pilot project facility within ERSO, and in 1977-78, the first trial run of wafers was produced. The objective was to transfer technology to local industry after the pilot production phase, while increasing production capacity and improving quality control.

Efforts of NSC

Taiwan's National Science Council (NSC) had begun a major drive in 1974-75 to establish IC research locally. Under its "large-scale project on microelectronics", various labs were set up in IC process technology, personal computer applications, and automatic technologies. Professor Hu Ting-hua was in charge of the labs for IC process technology at Chiao Tung University. In 1975, he left for ERSO, taking many students and faculty with him, thus further contributing the buildup of human capacity at ITRI/ERSO.

ICs go Commercial: the Creation of UMC

A primary goal of the state's semiconductor project was to move technology out of the lab and into the private sector. To this end, Shih Chin-tay, one of the key engineers recruited by Dr Pan and trained at RCA, and his boss at ERSO, Hu Ting-hua, submitted a business proposal in 1978 for a joint state-private semiconductor venture to the MOEA. The MOEA then tried to interest private sector entities in investing, but they were reluctant, viewing ICs as a highly risky business. Eventually, though, the government did manage to get some contributions from them, albeit small. ITRI also created the subsidiary Industrial Technology Investment Corporation

---

24 A wafer is a round disc of semiconductor material, most commonly Silicon. They are a few millimeters thick and are available in a variety of diameters. Many integrated circuits are simultaneously fabricated on wafers. (Taken from http://www.icknowledge.com/glossary/w.html)

(ITIC) to reassure private companies; ITRI provided 40 percent of ITIC's support for the IC venture; the rest came from banks and private investors.

The result was the creation of United Microelectronics (UMC), a joint state-private sector venture. Much of the plant, equipment and trained personnel were transferred by ERSO, which continued with the pilot production of wafers in its own facility. After UMC was formed, however, a conflict arose: its management wanted ERSO's pilot facility closed down; ERSO was turning out 15,000 wafers a month, and had the same products and market channels as UMC. UMC claimed that there was no need for government, via ERSO, to stay in the business of wafer production and sales. Shih Chin-tay and others remained firm, however, that ITRI needed to stay involved to ensure continuous R&D. ERSO continued production.

Developments, 1979-1985

In 1979, professors were invited to work at ERSO to gain industrial experience. Also around this time, some ERSO engineers were in favor of the idea of separating manufacturing and design in the IC project. Thus Taiwan would develop a design methodology and train engineers who would become small entrepreneurs.

Sun became Premier in 1979, and, no longer directly overseeing ITRI/ERSO, created the Science and Technology Advisory Group (STAG), through which he could remain involved in their functioning. STAG consisted of foreign advisors with experience in the semiconductor industry. Sun also approved a plan for the future of science and technology in Taiwan in which he identified eight high-technology areas, including ICs.

UMC had become highly successful by this time, its wafer production and sales overtaking ERSO's. It began to make its own R&D and licensing agreements with US companies, and, in 1985, went public, with the government remaining a minority shareholder.

In 1982, it was decided that ITRI/ERSO would focus the semiconductor program on VLSI[25] technology. The objective was to provide a base for expanding Taiwan's R&D capacity. Some felt that the plan was too ambitious, since even Canada and France had tried and failed. Some felt that too many resources were going into semiconductors, at the expense of biotechnology and automation. Also, the industry

[25] Very Large-Scale Integration; integrated circuits with greater than 100,000 transistors. (http://icknowledge.com/glossary/v.html)

disagreed that ITRI should have a part in this; UMC wanted to do the VLSI development itself. STAG, however, supported ITRI/ERSO.

VLSI and the Formation of TSMC

ERSO began to support VLSI design projects in universities; professors were invited to ITRI over the summer and encouraged to do VLSI wafer design projects with their students, which ITRI would then process. The initial years of the VLSI project encountered difficulties, however, due to the reluctance of the private sector to invest, and the reluctance of the state to commit large amounts of capital.

Eventually, the government formed a second joint venture company, Taiwan Semiconductor (TSMC), with contributions of 49 percent, 27 percent and 24 percent from the Taiwan government, Philips, and local private investors respectively. TSMC aimed at being a world-class semiconductor facility, specializing in manufacture but not design or marketing. It also served small design houses located at HSIP; within a year after TSMC's formation, forty chip design houses were set up there. After the success of UMC and TSMC, several other private semiconductor firms started up, among them Winboard Electronics, the founder of which left ERSO and took a large number of its personnel with him to start the company.

Given the increasing number of actors involved in semiconductors, STAG felt the need to increase its organizational capacity. It set up technical review boards that would present recommendations to ITRI. STAG eventually persuaded ITRI/ERSO to move ahead with the risky business of memory chips, so that it could become a world-class competitor independent of foreign manufacturers.

DRAM[26] Chip Production

Submicron technology, necessary for the production of DRAMs, became ERSO's new focus by 1988. Taiwan's six existing IC companies were invited to become part of a research consortium with ERSO, with the government covering all equipment expenses and half of the ongoing costs. After much discussion, and spurred by Acer's decision to move into DRAMs, ERSO/ITRI/TSMC eventually moved into DRAM technology.

---

[26] Dynamic Random Access Memory; a type of semiconductor memory where data may be accessed at random and data must be continuously refreshed. DRAMs will only hold data for a few milliseconds so the data must be read and re-written every millisecond or so. (http://icknowledge.com/glossary/d.html)

The history of Taiwan's success with ICs, it can be seen, features ITRI/ERSO playing a leading role in product research, development and design, as well as being a chief coordinating institution between state, industry and academia. Taiwan's first two semiconductor companies were both spin-offs of ERSO (Table 4.1 shows other ITRI spin-off companies). The emphasis was heavily on semiconductor technology initially, since this is what the Taiwan government singled out to give its economy a new direction.

Table 4.1 ITRI's Role: Commercialization and Entrepreneurship

Year	Company (ITRI Spin-off)	Details
1979	UMC	First 4" wafer fab[27] in Taiwan; US$1,886 million (2001)
1987	TSMC	First 6" wafer fab in Taiwan; US$3,726 million (2001)
1988	TMC	First mask[28] fab in Taiwan; US$84 million (2001)
1994	VISC	First 8" wafer fab in Taiwan; US$266 million (2001)
2001	TTLA	First TFT-LCD alliance in Taiwan

Source: Shih (2002)

ITRI TODAY

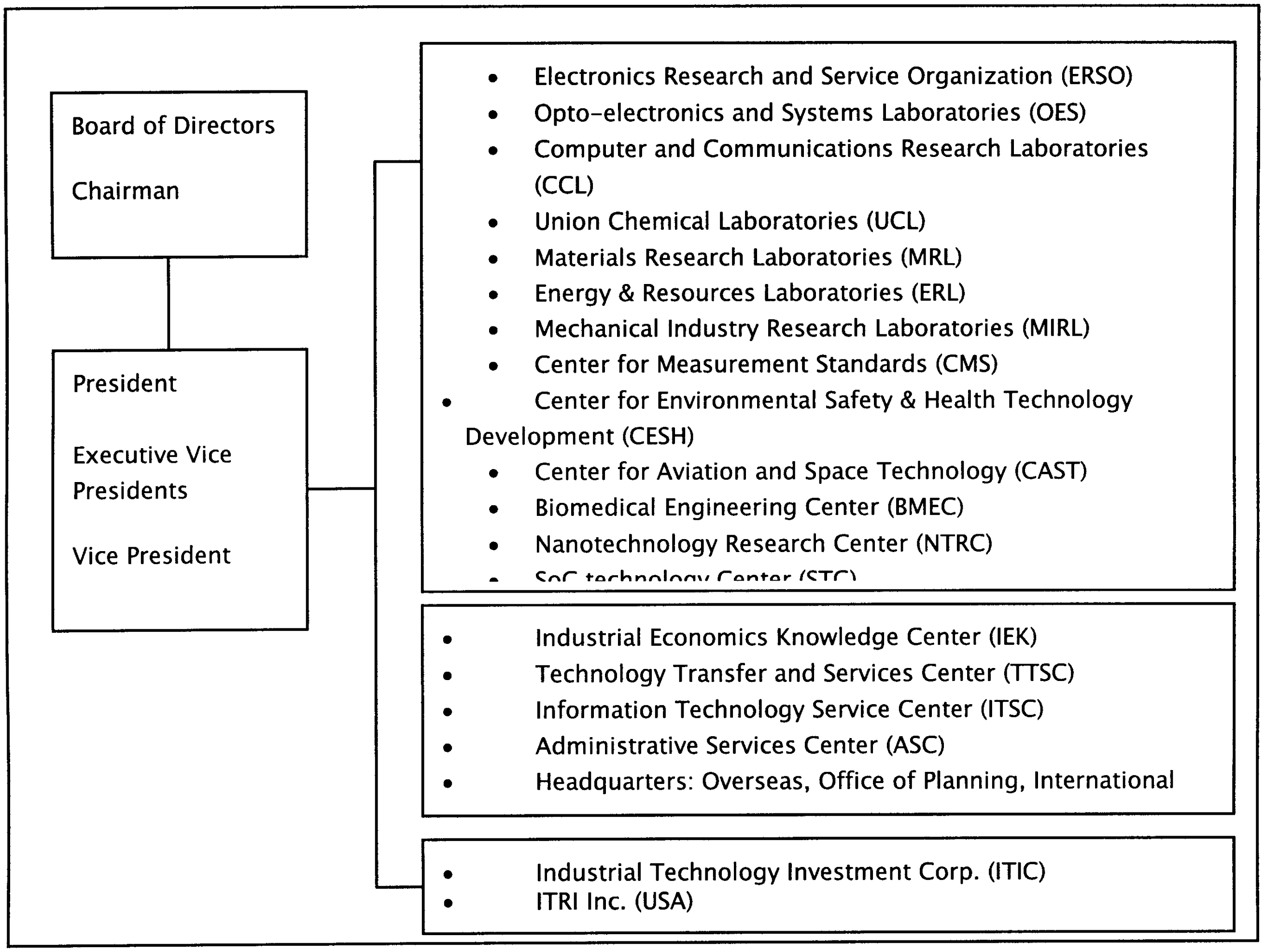
With eleven labs and research centers, plus a large incubation facility for industry, ITRI conducts high-quality R&D in a range of high-tech fields. It has over 6,000 personnel, of whom about 4,600 are research staff. Figure 4.1 shows ITRI's labs and centers.

---

[27] "Wafer fab: is a facility where the wafer fabrication process is performed (http://icknowledge.com/glossary/w.html)

[28] A mask is a glass plate with a pattern of transparent and opaque areas used to photolithographically create patterns on wafers. A mask is commonly used to refer to a plate that has a pattern large enough to pattern a whole wafer at one time (http://icknowledge.com/glossary/m.html)

Fig. 4.1 Overview of ITRI Centers and Laboratories



Source: Adapted from Hsu, 2003

Main Research Areas[29]

ITRI's main research areas are shown in Table 4.2 below.

---

[29] These descriptions are based on those provided by the ITRI website.

Table 4.2 ITRI's Main Research Areas

RESEARCH AREA	GOAL	TECHNOLOGY DEVELOPMENT
Communication and Opto-electronic Technology	To master energy saving and minimization technology by establishing system-on-a-chip, nano-electronics and opto-electronic technology. Also, to reinforce inter-laboratory collaboration on module and component development based on intelligent opto-communication systems.	ITRI is adopting mobile communication and broadband internet technology development and application as the core of its research in the communication and opto-electronics field. The Institute takes advantage of the existent basis of wireless communication, broadband communication, IC design, intelligent information and opto-electronic information technology. ITRI is moving toward advanced research areas such as beyond 3G network technology, wireless data access, broadband data access technology, intelligent opto-communication network technology, human interface and information technology, advanced flatpanel display technology, and nano electronic technology.
Materials and Chemical Technology	To accelerate the local industrialization of key materials and components supplied for domestic semiconductor, opto-electronics and communications industries; to help traditional plastics, metal and certain electronics companies upgrade through close industry cooperation; to concentrate on innovative, advanced technology research, developing next-generation materials with the aim of maintaining Taiwan's competitiveness in the global market.	ITRI focuses on research of electronic packaging, electronic materials, specialty chemicals, functional polymer materials, catalysts and precision chemical engineering process, high-performance metals, and nano-technologies for materials. It has developed bi-layer silicone-containing photoresist, nano-sized pigment, resin coated copper foil materials, polymer lithium battery, metal semi-solid forming, metallocene-based COC and opto-electronic applications, hi-tech fibers, high resolution advanced recordable media, electro-acoustic composite and nano-composite materials.
Precision Machinery and MEMS Technology	Innovative technology development, such as micro and nano technologies, MEMS technologies, precision machinery, semi-conductor process equipment, automation, electronic machinery, power train system and avionics retrofit, etc. ITRI aims to upgrade domestic electronics, opto-electronics and biomedical industries, and to develop new industries.	Technology development: ITRI combines its strengths in electronic engineering, measuring, aerospace and automation technologies. Main research results include advanced LIGA-like process, nano measurement, micro systems & key components design and fabrication, common engine, electrical scooter, PC based controller, computer integrated manufacturing system, and avionics information and entertainment system etc.
Sustainable Development Technology	To improve business operations, fortify market competitiveness, increase resource utilization, and reduce working environment hazards.	Cross-disciplinary sustainable development research that integrates energy and resources technology, fresh-water and ocean resources technology, land protection technology, industrial safety and hygiene technology, and environmental technology.
Biomedical Technology	To contribute to developments in pharmaceuticals engineering, medical engineering and human tissue engineering, by adopting genomics technology as a core research area.	Key research projects include biochips, bioinformatics, biomaterials, regeneration, medical electronics, medical image, herbal therapeutics and peptide drug development. Clinical studies are conducted in collaboration with universities and hospitals such as National Taiwan University Hospital, Veterans General Hospital, Tri-Service General Hospital, Chang Gung Memorial Hospital and the National Cheng Kung University Hospital. Several joint research programs are also in progress with international biomedical research institutes such as MIT and CSIRO.
Nanotechnology	To establish platform technologies to support nanoresearch, such as processing, measuring, modeling, and equipment development.	The primary nanotechnology research in ITRI covers nano-materials, nanoelectronics and nano-biotechnology. Main research areas include Integrated circuit, electronic packaging, display devices, data storage, opto-communication, nano-biotechnology and energy technology, such as microfuel cells. Major research results include several world leading technologies, such as nano pigment, paint, dyestuff, advanced recordable media inorganic, carbon nanotube field emission display (CNT-FED), SiGe quantum devices nano-composite and high capacity battery and capacitors.

The Funding of ITRI

ITRI obtains half of its funding from the government and the other half from industry. In 2002, it had a revenue of US$475 million, which was distributed as follows (Hsu, 2003):

Communication and opto-electronic technology	47%
Precision machinery and MEMS technology	26%
Biomedical technology	13%
Advanced materials and chemical technology	12%
Sustainable development technology	5%
Others	2%

ITRI has decided to allocate NT$23 billion to pursue nanotechnology research over the next six years; NT$9.5 billion for biotechnology research from 2002-04; NT$7.6 billion for research on system-on-a-chip for the next five years; and has recently spent NT$12.84 billion for communication R&D for 1998-2003 (Shih, 2002).

One concern with the rigid cost-sharing agreement with MOEA, however, is that it becomes necessary to conduct mostly those projects that are near commercialization (WTEC, 1997). Thus during discussion about future research projects in nanoparticle technology, this arrangement posed an obstacle to doing electro-optical projects (*ibid.*). The focus was therefore directed more towards coating-and-structural-materials-related applications.

ITRI's impacts and accomplishments

Upgrading Existing/Traditional Industry

ITRI has contributed to the upgrading of the sporting industry, in improving tennis rackets and golf clubs. It has also improved plated plastics, machine tools and parts, fabrics, and pharmaceuticals. A particularly successful case is that of the bicycle industry. In 1987, ITRI's Materials Research Lab helped the company Giant develop a carbon fiber bicycle frame, which was remarkably successful. By the 1990s, the Lab had secured 17 patents pertaining to the bicycle derailleur (Amsden and Chu, 2003). Taiwan currently produces 60 percent of the world's carbon fiber composite bicycles (Lin, 2003).

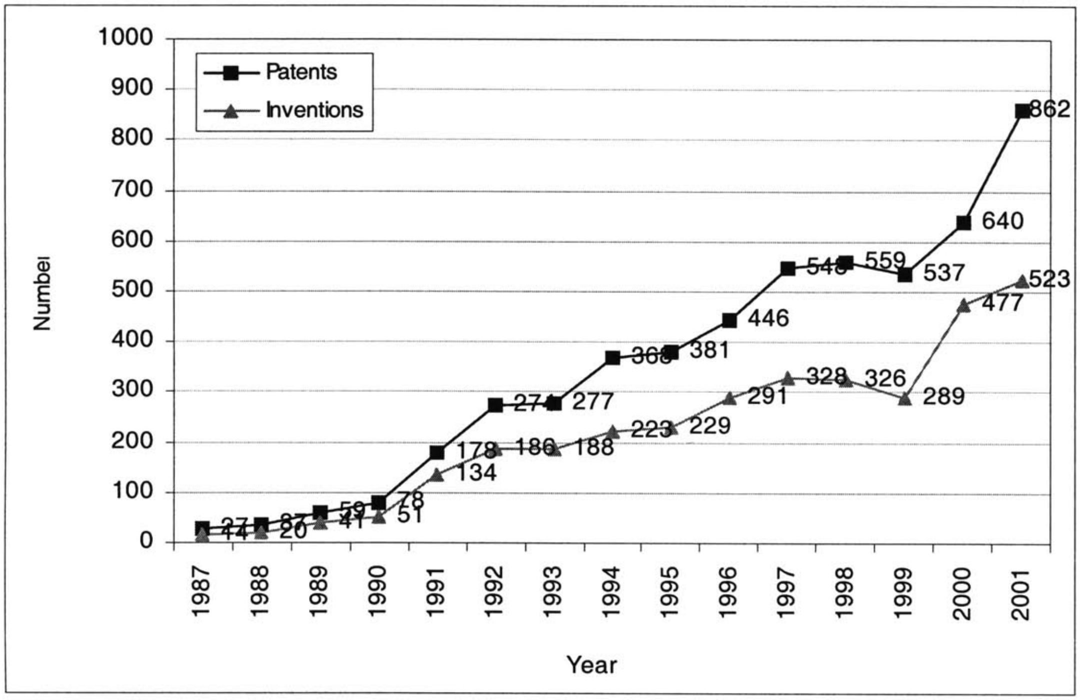
Promotion of High-Technology Industry in Taiwan

In addition to spinning off several semiconductor firms (discussed earlier) and thus largely to be credited for Taiwan's current global rank of fourth in the IC industry, CD-ROMs are another success story. In 1992, ITRI was asked by MOEA to develop CD-ROMs. The project involved 25 firms in joint development and technology transfer. Four patents were secured for CD-ROMs and twenty-four for CD-ROM pickup heads (Amsden and Chu 2003). Firms that acquired CD-ROM technology from ITRI were able to begin assembly operations immediately. Taiwan's share of CD-ROMs output rose from 1 percent in 1994 to 50 percent within a space of five years (*ibid.*). Another success story is that of the notebook PC industry, the evolution of which ITRI has been heavily involved in. By 2000, Taiwan was producing nearly 65 percent of the world's notebook PCs (Lin, 2003). Further, ITRI has been involved in the design and production of the many computer peripherals that Taiwan now has high global output in (for details on Taiwan's share of global output, see Chapter 3).

Innovation in Taiwan

Given the state-of-the-art facilities, large budget and highly skilled human resources at its disposal, ITRI has been able to build a remarkable patent record. Figure 4.2 shows ITRI's patents and inventions from 1987 to 2001, while Table 4.3 shows ITRI's patents in comparison with those awarded to high-tech companies in Taiwan. ITRI has the most.

Fig. 4.2 ITRI's Patents and Inventions, 1987-2001



Source: Shih, 2002

Table 4.3 Top 10 recipients of US Patents for Taiwan, 1980-1996

Recipient	Patent owner	Number of Patents
Industrial technology research Institute (ITRI)	G	602
United Microelectronics Corp. (UMC)	G	317
National Science Council	G	132
Taiwan Semiconductor Mfg. Co. Ltd. (TSMC)	G	89
Acer, Inc.		59
Winbound Electronics Corp.		25
IBM	F	23
Honeywell Inc.	F	21
Giftec Ltd.		21
Greenmaster, Industrial Corp.		20

G= government-owned

F= foreign-owned

Source: adapted from Amsden and Chu (2003)

Incubating New Firms

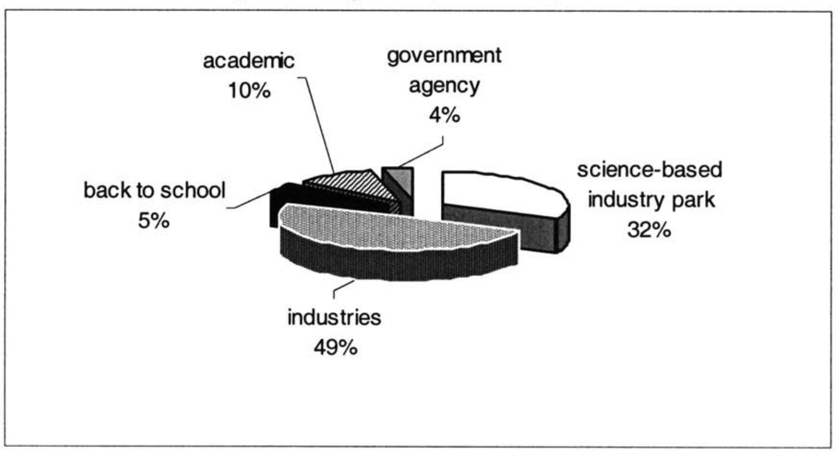
ITRI targets existing companies for joint R&D and also selects entrepreneurs for its incubation facility, in its Open Lab. So far, 4,350 researchers have participated in joint research from over 167 companies (Hsu, 2003). Currently there are 980 researchers from 50 companies onsite (*ibid.*). To date, 151 projects have been conducted, with a total participating company investment of US$360 million (*ibid.*).

The incubator facility has been responsible for the formation of 96 new companies, with a total capitalization of approximately US$1.2 billion (*ibid.*). ITRI's is believed to be the world's most productive incubator (*ibid.*).

Human resource development in Taiwan

One of the most important services ITRI may have rendered Taiwan is in terms of its human resource development. Through training, joint R&D and employment provision, ITRI has trained nearly 16,000 Taiwanese in various industrial fields since 1973. Many of them have now moved on to various other institutions and organizations (see Figure 4.3, below). ITRI served an immensely important role in the 1980s in helping to reverse the brain-drain from Taiwan (Lin, 1998). After finishing post-graduate studies, many students tended to find jobs abroad, mostly in the US, since opportunity in Taiwan was limited. ITRI, because of its early engagement with cutting edge technology, provided many with a compelling reason to come back. Several of the returning expatriates contributed immensely to development in Taiwan upon their return.

Fig. 4.3 The Repository of Industrial Human Resources (1973–May 2002) Total: 15,735



Source: Shih, 2002

Working with Other Institutions in Taiwan

One of ITRI's most outstanding features is its collaborative work with state, academic, and industrial actors. It has strong links with the Hsinchu Science-Based Industrial Park, where firms move to after graduating from ITRI's incubation facility. ITRI also has strong links with universities and national R&D centers, with whom it collaborates in research. It works very closely with Taiwan's private sector, keeping a close eye on industrial needs and future trends, and helping entrepreneurs establish new business. Being directly under the MOEA, ITRI has profound state ties; its operation is governed by various decisions and recommendations made a state level.

International Linkages

ITRI's close links with Taiwanese- and Chinese-Americans abroad have been extremely useful in terms of technical advice, information on latest industrial trends, and facilitation of technology transfer. The research links with scientists, engineers and firms in California's Silicon Valley have been particularly useful. ITRI also has partnerships with academic and industrial institutions worldwide. Currently, these are in the US, Canada, Germany, UK, Netherlands, CIS, Israel, Japan, Korea and Australia (Hsu, 2003). Further cultivation of worldwide partnerships is one of ITRI's goals for the future.

Conclusions

This chapter has presented an overview of ITRI's functioning as well as an assessment of how ITRI has contributed to Taiwan's development. It has done so through upgrading traditional industry, exploring high-tech industry, launching spin-off firms in semiconductor technology, helping entrepreneurs start new business, doing collaborative research projects with academia and industry, and contributing heavily to human resource development in the state in general.

The next chapter will show where ITRI fits within Taiwan's innovation system. It will assess whether ITRI has been the chief institution that innovation in Taiwan hinges upon. Importantly, it will also look at the feasibility of replicating an 'ITRI-approach' in developing countries to promote economic development. The case of Pakistan is briefly assessed in this regard.

5 DISCUSSION

Introduction

This chapter has two parts. First, it will assess ITRI's place within the Taiwanese innovation system. This includes an examination of how crucial a role it played, both directly and through its links with other institutions across sectors. The chapter also looks at general lessons regarding high-tech development that can be learned from this study, particularly as they relate to developing countries in their attempt to 'catch-up'. Secondly, the chapter takes a developing-country example, Pakistan, and briefly overviews its institutional system and efforts to promote high-tech development in order to see whether an ITRI-style approach can be of relevance and use there. The example of Pakistan serves to highlight some prerequisites that may be necessary in order for an ITRI-approach to work in developing countries, and which factors can stand in the way of its success.

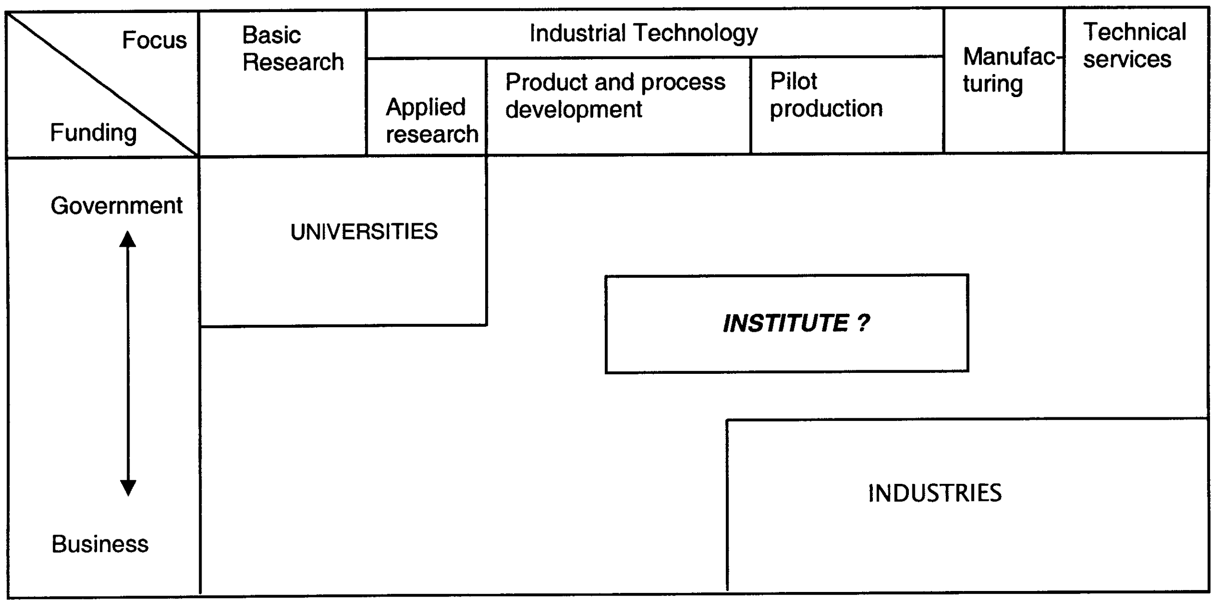
ITRI IN TAIWAN'S INNOVATION SYSTEM

The previous chapter looked at ITRI as an institute, and covered its origins, departments, research areas, and accomplishments. This section will build upon that information to focus on the issue of main interest: where does ITRI fit in the Taiwanese innovation system? This requires an idea of the interworkings of the various components of the system, and an assessment of the scope of ITRI within these.

The Role of the Institute Within the NIS

Lin (2003) presented a national innovation system model that was reproduced in Figures 2.2(a) and 2.2(b) in Chapter 2 (see p.19). Emphasizing that it was not merely the components, but the *relationships* between them that define an innovation system, he suggested that "the institute(s)" plays an important role in linking both ends of the innovation process: research and commercialization (or academia and industry). Just what role the institute plays in bridging the gap - the nature and extent of the various functions it takes on - is a factor largely responsible in distinguishing one country's system from another. Figure 5.1(a) reveals the various functions that need to be carried out within a technological innovation system and makes it clear that technological development institutes need to be a part of such a system.

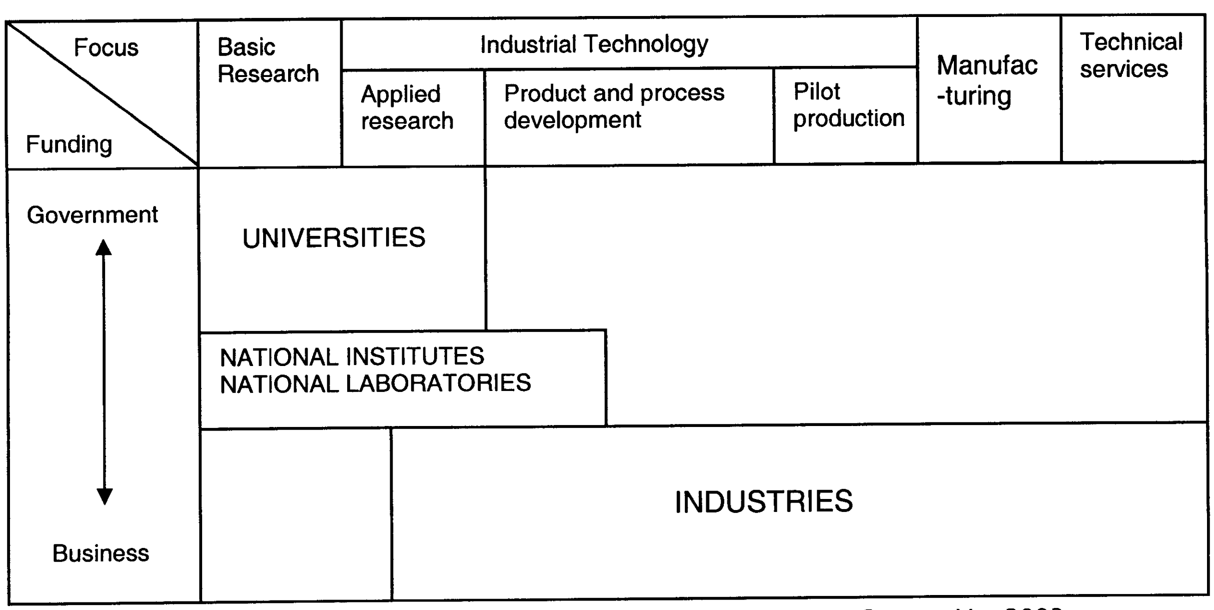
Fig. 5.1a National Innovation Systems and the Role of the Institute



Source: Lin (2003)

In Figure 5.1(b) Lin has modeled the innovation system of the United States. Both the academic sector (universities) and the private sector (industries) are very strong, and work closely with each other. Certain national institutes work to further bridge any gap between the two.

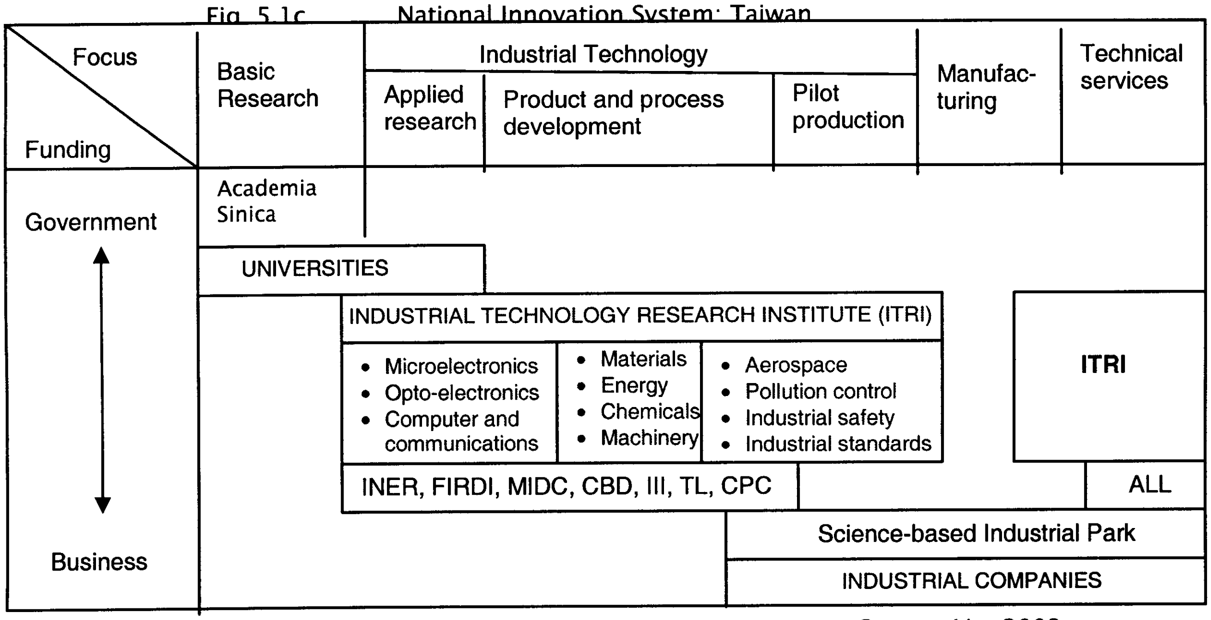
Fig. 5.1b National Innovation System: USA



Source: Lin, 2003

The difference in Taiwan's system, Lin (2003) claims, is that, traditionally, the gap between universities and industry has been large. The "institute", ITRI in this case, conducts research through its laboratories, *and* makes commercial products. It thus plays the crucial role of filling in and bridging the gap between research and commercialization, and works closely with state and industry (see Fig. 5.1(c)). Further, ITRI has helped Taiwan establish indigenous technology capacity.

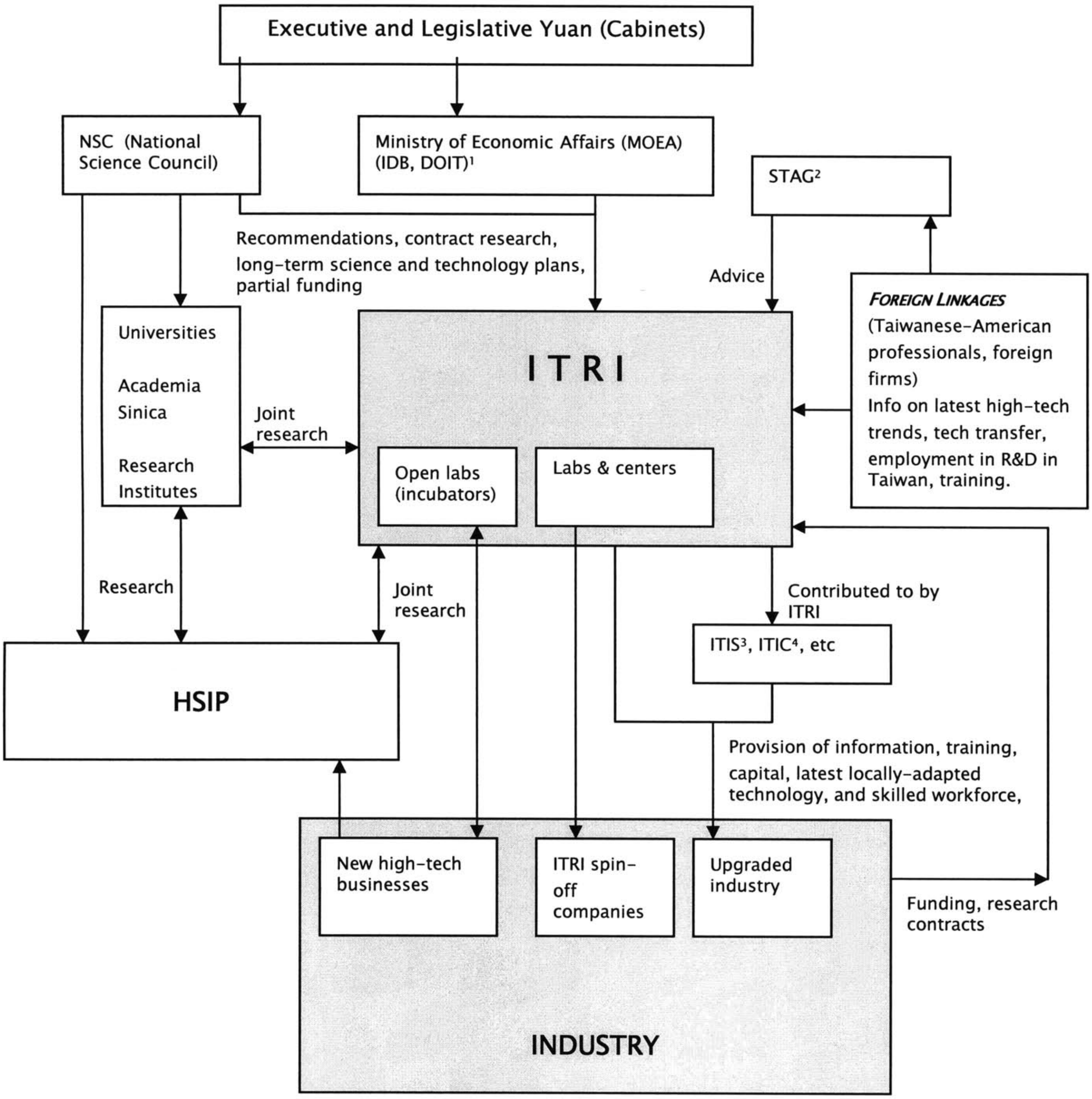
Fig. 5.1c National Innovation System: Taiwan



Source: Lin, 2003

The various functions served by ITRI and the relationships between the various institutions involved in promoting high-tech R&D are displayed in the model in Figure 5.2.

Fig. 5.2 ITRI in Taiwan's Innovation System



[1]Industrial Development Bureau (IDB) and Department of Industrial Technology (DOIT).
[2]Science and Technology Advisory Group
[3]Industrial Technology Investment Corporation
[4]Industrial Technology Information Services

As a large research and technology-implementation institute that addresses both the government's development goals for the future and the needs - both current and future - of Taiwan industry, ITRI has possessed the flexibility, the technical expertise, and the domestic and international linkages required to play an instrumental role in Taiwan's high-tech development, particularly electronics and IT.

Evidence has been presented thus far that ITRI:

- is a means for the Taiwan government to conduct R&D in 'strategic' high-technology for the future;
- keeps apace with latest high-technological developments abroad, targets certain of these to have brought into Taiwan, and conducts its own research on these for adaptation and transferal to local industry;
- makes research results and advice on technology implementation procedures widely available to domestic industry;
- helps entrepreneurs start new high-tech business through its incubator facility. These then move to the Hsinchu Science-Based Industrial Park;
- provides training and education on high-tech development issues through conferences, training programs, and joint research with other institutes;
- is a means of encouraging Taiwanese- and Chinese-American engineers and scientists to return to Taiwan (by working at ITRI or the HSIP);
- has contributed greatly to Taiwan's highly skilled industrial research and professional force by migration of its employees to industry;
- has spun-off at least two of Taiwan's most successful IT companies.

The question of great interest now is whether this highly successful institutional approach can be of relevance to developing countries today to help them pursue their technological development goals.

THE 'ITRI APPROACH' IN DEVELOPING COUNTRIES

As discussed in Chapter 2, many developing countries are in dire need of improving their existing innovation systems, in order to push technological catch-up. A continuing cycle of transfer of technology from industrialized countries will not be sufficient to bridge the current gap between developed and developing countries, nor may such an arrangement best meet the local industrial needs within developing countries. Developing countries need to focus on technologies that can meet their particular development goals, and develop the human capability and national organizational structure to have these transferred, adapted and disseminated to local industry - as Taiwan did. Developing countries will probably start of with technology 'imitation', rather than 'innovation', but, as has been stated earlier, the subset of skills required for imitation are a subset of those required for innovation. Technological learning will require focused, incremental efforts, and the creation of new skills and relationships. These concepts are in keeping with the new 'endogenous' approach towards innovation in developing countries.

Certain things stand out about Taiwan's ITRI-centered innovation system that have important implications for developing countries:

- *It is a streamlined system with easily identifiable components.* There is little room for replication of tasks within the system, except in the case where various research institutes may be conducting cutting-edge research on the same technological issues, which would, of course, be a desirable situation. However, there is a strong tendency towards joint research. ITRI's role is unique. Since it serves several crucial functions, this uniqueness is important in allowing ITRI to function as a sole authority and in placing a high degree of responsibility on the institute.

- *The government has played a leading role in guiding Taiwan into certain technological fields for development.* Strong political leadership was crucial. While the advisability of such levels of government involvement has been debated by some, there are those who argue that in its initial stages of technological development, at least, a strong government role is desirable for a country. Technological development is necessarily a long-term goal; the constancy and skilful planning with which a government pursues its goals are factors that rest heavily on political stability within a country. This, Taiwan was fortunate to have.

- *Several authors have pointed at Taiwan's work ethic as a key factor in its early success in development.* The fact that the Taiwanese were educated, hard-working and willing to learn speaks for the good educational programs put in place by the government and a system of incentives for hard work - as well as disincentives for slacking off.

- *Taiwan utilized its capital and human resources efficiently.* This ties in with the establishment of only as many national institutions as the government felt were necessary, and merging institutes to pool resources and prevent replication of tasks.

Now a developing-country example is taken to see what kinds of changes would be necessary for the Taiwanese, ITRI-based, innovation system to work - and whether this would be desirable. The country examined is Pakistan. The next section will outline the background of technological development in Pakistan, including positive measures being taken and major hurdles that exist, and then an assessment of how an ITRI-approach could be applied.

A MINI-CASE STUDY: INNOVATION IN PAKISTAN

Background

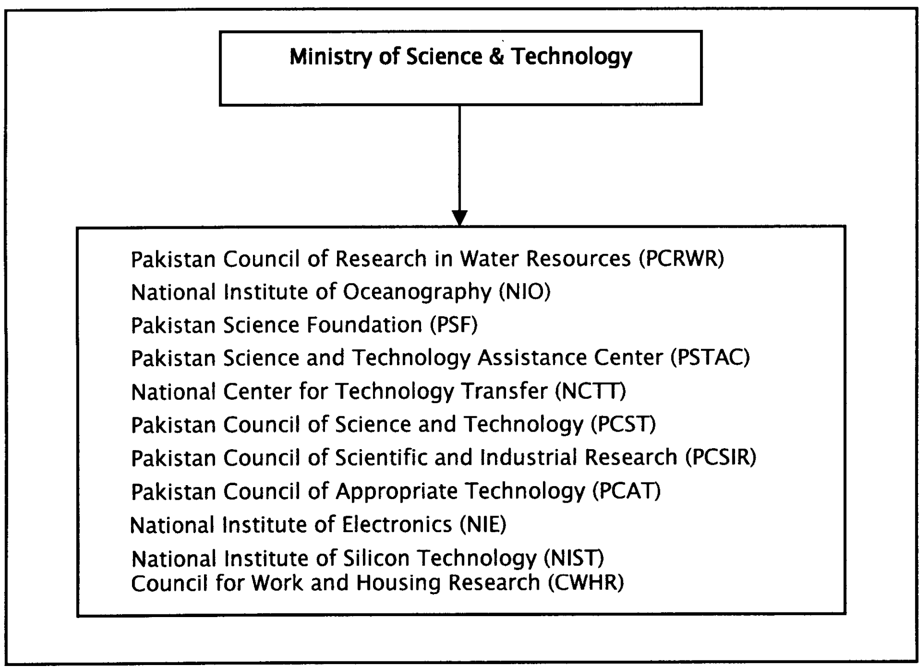
Pakistan, with a population of 153 million, of whom only 46 percent are literate (UNDP, 2002), is a technologically backward country that has been - and still is - heavily dependent on agriculture; this sector accounts for employment of 60 percent of the country's labor force, and 25 percent of the GDP (Khan and Iqbal, 2000). Most of the country's exports are agriculture-related, notable exceptions being from the surgical instruments and sports goods industries. Its domestic industry mostly comprises small and medium highly labor-intensive enterprises, and foreign investment has been low, although successive governments have constantly tried to rectify this.

Pakistan has a per capita GDP of US$ 800 and is heavily dependent on foreign aid. Education and health are sectors that have been largely neglected due to the country's overriding security concerns, which have resulted in large proportions of the budget being diverted for military purposes (US$2.6 billion in 2001; CSIS, 2002).

Although a large proportion of funds have been going into Pakistan's nuclear energy program, other aspects of science and technology have been back-burner issues for the country until very recently. A plethora of national research institutes and university research departments were established, but were under-funded and understaffed with qualified personnel. As one government researcher at the Pakistan Council for Science and Industrial Research (PCSIR) said: "I left. It was impossible to do any real research. We kept running out of chemicals for basic experiments" (pers. comm., 2003). Pakistan only has 112 PhD-holders and engineers per 1 million of its population (Ali, 2001). Most of the past ministers in Science & Technology have not hailed from scientific backgrounds.

Pakistan has a total of 130 research organizations working under different Federal and Provincial Ministries in a variety of sectors. Fifty-eight of these function at the federal level under as many as 12 ministries, conducting from basic research to information dissemination. The various institutes under (MOST) are shown in Figure 5.3.

Fig. 5.3 R&D Institutes under the Ministry of Science and Technology



Source: based on ATIP (1998)

Their functions range from giving MOST advice (PCST), to funding allocations (PSF), to supporting other institutions involved in technology transfer (NCTT), to conducting applied research (PCSIR, PCAT), etc.

However, there are also several other institutes doing related research working under other ministries. For example, the Pakistan Industrial Technical Assistance Center (PITAC) is under the Ministry for Industries, and conducts research on environmentally-friendly technology for industry; the Central Telecommunication Research Laboratories (CTRL) is under the Ministry of Communications; and space, atomic, agricultural and environmental research is also carried out in institutes under different ministries. There is very little joint research between these various institutes.

Efforts being made in S&T

Appointment of Minister with Science Background

For the first time, Pakistan's Federal Minister for Science and Technology, Prof. Dr Atta-ur-Rahman, is highly qualified for the task, having taught Chemistry at Cambridge University, UK, and currently heading the prestigious HEJ Institute for Chemistry research in Pakistan. Appointed in 1999 by President Musharraf after a military coup, Dr. Rahman has been making a tremendous effort to boost S&T research in the country. The Ministry of Science and Technology has made available a number of new fellowships and scholarships, is starting up business incubators, and is heavily emphasizing IT development.

Focus on IT and human capacity building

Pakistan has a US$1 billion private sector telecom operation and IT industry. For the first time in the country's history, Minister Dr. Rahman has formulated an IT-development plan. The reason for choosing IT, according to the Minister (Rahman, 2000), is that it requires less infrastructure investments and sophisticated technologies than several other cutting-edge technologies. The thrust is software development, and current areas of focus are service industries such as data entry, call centers, and system integration. The IT industry is facing several problems, however, which are discussed in the next section.

President Musharraf allocated US$83 million for IT development for the period 2000-2003 to the Ministry of Science and Technology (MOST) and gave the Minister free rein in its use. Most of these funds (60-70 percent), according to the Minister (in Rizvi, 2003), are being used for human resource development. The various IT-enhancement projects underway are:

- granting endowment funds to universities to facilitate higher education in IT;
- providing support to universities for capacity-building of IT departments (hiring foreign-qualified faculty, training in-house faculty, etc.);

- starting projects to develop the local IT industry (local software development, helping local companies prepare for international business, sponsoring and assisting local companies in IT exhibitions, etc.);
- infrastructure development
- e-commerce studies.

IT institutes are being upgraded, and some are being accorded university status. The government has also put several incentives for IT investment in place, such as zero percent income tax for the next five years on software houses, zero percent duty on computers and computer parts, the ability of software companies to retain 35 percent of export earnings in foreign currency accounts, fifty percent rebate on the income tax of IT professionals, and the easy availability of loans for software houses (Rahman, 2000). A US$50 million venture capital fund has been created by Pakistani IT professionals and entrepreneurs based in the US. Foreign companies have also begun investing in Pakistan, such as IBM, Oracle, CISCO and CERN, who are setting up training centers and academies.

A new institute is being proposed for IT research in Islamabad, Pakistan: the National Institute of Information Technology (NIIT). However, some criticism has also been raised at the establishment of yet another institute (Professor Daudpota, below).

Regional collaboration

Large efforts are being made in regional collaboration in S&T. One example is the OIC (Organization of Islamic Conference) Standing Committee on Science and Technological Cooperation (COMSTECH). The objective is to boost collective scientific capacity through joint research, fellowships, training programs etc. However, COMSTECH is severely hindered by funding shortages; its member countries do not contribute enough for much progress to be made.

Problems Facing the IT Sector

Although efforts are underway to address this, progress in Pakistan's IT sector has been relatively stagnant over the past few years (unlike that of its neighbor India's). An IT revolution in the country would greatly benefit both the public and private sectors, providing many new jobs (including in supporting industries), more foreign exchange in the country, and direct as well as indirect tax revenue for the government.

Four areas need urgent attention (*ibid.*) for the IT sector to succeed[30]:

- **Education:** currently, not enough equipment, scholarships, and the quality of education provided in public institutes lags far behind that of private institutes.

- **Facilitate IT Businesses:** The government has currently allowed one company, PTCL, the monopoly over high-speed internet connections in the country, and the rates it charges are very high. Competition needs to be introduced to bring prices to affordable levels, or the government should subsidize investment in this area. At present IT businesses are also subjected to a lot of red tape, which dampens their motivation. Further, international training courses and conferences are difficult for professionals to attend due to the immense difficulties in procuring visas, which the government could attempt to facilitate through legal agreements.

- **Create Presence in International Markets**: International market presence is necessary for Pakistani companies to be able to compete effectively with established companies from other countries. Since Pakistani companies have very small budgets, they need to forge partnerships or joint venture agreements with people or companies that already have a presence in the international market. So far, these partnerships have been forged with Pakistanis residing overseas. In an attempt to bring Pakistanis from both continents to work together, President Musharraf had sent Mr. Toheed Ahmad as Pakistan's IT Consul General to the Silicon valley in the US in 2002. However, in less than 6 months, Mr. Ahmad had to close down operations, due to economic circumstances in Pakistan, he claimed, particularly withdrawal of foreign investment after events relating to September 11, 2001.

- **Encourage Private Investment:** Private investment, and not government funding, is the main solution to the Pakistan IT industry's problems. However, fraud, and fear of fraud, prevent people - even foreign-based Pakistanis - from investing in Pakistan. A smooth legal framework to address this needs to be created. Tax incentives for investors in IT would also be helpful. Pakistanis overseas - who are the largest group of those investing in

[30] These are mostly taken from Khan (2000).

Pakistan, are not very organized as a group where it comes to aiding Pakistan - this needs to be changed. An important step was the organization of the Overseas Strategic Advisory Board in San Francisco, USA, by the new Minister for MOST.

Applying the ITRI Approach to Pakistan's IT Institutions

A number of IT research and educational institutes have been established in Islamabad, Pakistan's capital city. Yet another has been proposed, the National Institute for Information Technology (NIIT). The idea of combining these to form a large R&D/implementation institute in the fashion of ITRI not only seems like a good idea; it has been strongly recommended (without reference to ITRI) by one of Pakistan's Professors in Business and Innovation at Hamdard University, Islamabad. As Professor Daudpota (2000) brilliantly sums up:

> "There are many ways to set up a new institution. The one usually followed in Pakistan, particularly by the government functionaries, is to invest in mortar and brick...The other, more rational approach...is to ensure that existing sparse resources are optimized and used to the fullest.
>
> "An important area where this second approach can work is in the setting up of a national institute devoted to pursing information technology (IT). Run jointly by the public and private sectors, this autonomous institution should (a) coordinate national IT activities, (b) do research in areas of relevance to the country, (c) offer accreditation to other IT-related institutions, (d) offer high level degrees and (e) work closely with the Allama Iqbal Open University (AIOU) to set up the Virtual University.
>
> "Many of the technological breakthroughs of the coming decades will result from the synthesis of existing technologies, e.g. biotechnology and nano-technology. IT is a prime example of this: it developed out of a synthesis of electronics, communications and computer technologies.
>
> "Institutions that specialize in each of these three areas can easily collaborate on IT projects. ...the possibility arises for putting together an umbrella institution or board that can make a national IT institution flourish there. At present there is hardly any interaction between these institutions. Also, individually the performance of these institutions is not great."

Professor Daupota suggests combining eight existing IT-related institutes that are in close physical proximity to each other to form the NIIT. He warns:

> "All this may seem overly ambitious and, given our past record of poor management, an impractical idea. On the other hand, the alternative is the continual lack of focus in these national institutes and a waste of resources. The challenge is to tap these and to make a real difference in the IT arena."

Restructuring the system to a more ITRI-style approach, then, would yield the following main benefits:

- more coherence in the system as various institutions are merged
- this will conserve funding and allow pooled human resources
- there will be more structure and organization within the system

Stumbling blocks: Problems in Pakistan's Innovation System

We have seen that some innovation analysts in Pakistan support the idea of the ITRI approach towards innovation in IT in Pakistan. If this were done, then several of the existing public R&D IT institutes, both under the Ministry for Science and Technology and other government and entities, would be merged to form an institute with pooled resources, financial and human. Further, since an organization of this size would be able to give some solid help to industry in terms of research products and advice, as well as technology transfer, private sector contributions to the institute would expectedly be substantial. This section looks some "facts" of Pakistan's innovation system that could thwart the desired functioning of the ITRI-approach.

Government

Pakistan's government has been changing every few years. Each new government that came in represented a different political party, with its own agenda. The result has been that all S&T policies and actions put in place by one government would be undone by the next, sometimes out of a genuine belief that things were not being done the right way, and sometimes just for the sake of opposition. What is required is (i) either a national S&T that is not so dependent on the whims of passing governments, or (ii) a government that actually lasts for a certain period of time. President Musharraf claims that his delay in stepping down as Pakistan's President comes from his desire to lend stability to certain processes he has recently put in place.

Institutional

Pakistan has several national scientific research institutes, and is setting up research centers at various universities. However, even at this basic research level, equipment and facilities, as well as qualified personnel, are in short supply due to funding constraints. Applied research is in even worse shape; the Pakistan Council for Scientific and Industrial Research (PSCIR), with centers in various cities across the country, was formed with a view to conducting applied research: determining the economic feasibility of various products with a view to transferring them to industry. However, the institute has failed. The main reason, according to Minister Dr. Rahman, is that less than 0.3 percent of government funding to the institute was going into actual research, with 99.7 percent going into the payment of utilities and salaries. As a result, the number of PhD-holders working at the PCSIR has *diminished* from 280 in the 1980s to 70 today - an utter collapse. However, merging institutes could alleviate this situation, as well as that of universities.

Regarding national universities, Minister Rahman (in Rizvi, 2003) has stated that their budget is, on average, only 20 percent of the amount that universities in Bangladesh receive. PhD-holding manpower that has been retiring over the past 10-15 years is not being replaced, so that universities are faced with "a monumental crisis", and with the result that the universities have "in many cases shrunk to the level of high schools" (*ibid.*).

Social

Apart from the fact that most of the population is illiterate and of those that are literate, very few have higher-level qualifications in science and technology, a big problem in R&D in Pakistan is *providing people with the incentive to conduct research and work hard.* There is no adequate rewards system; once a government-research position is procured by a person, the job is more or less theirs until retirement. Since their work quality is scarcely monitored, and those that do work hard are not given any rewards or distinctions, there is actually a lot of incentive *not* to work hard. This is a social as well as organizational issue.

Organization heads

Pakistan's government research institutes are characterized by weak organizational leadership. In the case of Taiwan, it was seen that the personal efforts of people such as Sun, Pan, and Chintay were instrumental in making ITRI what it now is. Heads of government institutes lack motivation. Further, in many cases there is a strong cultural tendency to help friends and extended family members with appointments and benefits, rather than follow a strictly merit-based approach.

Educational

Schools are under-funded and it is difficult to obtain qualified teachers who will work for the salaries offered by government schools. Educational reforms are being put in place, however. Many of Pakistan's poorer children have traditionally studied at 'madrassas', where education was entirely on religious topics, in exchange for free shelter, clothing, and food for the children. President Musharraf recently made the study of science and mathematics compulsory at such schools, and also made university qualifications compulsory for electoral candidates (many representatives from religious parties tended to only hold qualifications from the 'madrasses' formerly). Positive changes are being seen here.

Economic

Attracting foreign investment has always been a goal of the various governments of Pakistan. However, due to unstable circumstances domestically (crime, unstable market, etc.), this has not been going well. Progress plummeted even further after September 11, 2001, with many foreign companies pulling out. Pakistan's domestic industry is upset about plans to increase tax revenues by raising taxes.

Conclusions from the Pakistan Assessment

- An ITRI type of approach towards merging R&D institutes can be of use in Pakistan. There is an over-abundance of IT institutes, and they are not performing very well individually.

- At present, the scope of such an ITRI-type institute would primarily be IT research, since manufacture is not really taking place. However, IT service provision is an industrial aspect that such an institute could help with.

- Several factors stand in the way of an ITRI-approach working as it should, at present, However, **all** these factors are such that they need to be gotten rid of regardless of the innovation approach adopted.

The Funding Question

While the ITRI-approach towards high-tech development could play an extremely useful role in developing countries such as Pakistan, there will always be the question of how to mobilize capital for such a system. Taiwan, through prior well-planned economic and industrial policies, was not in the cash-strapped position that many developing countries are in today. For a large-scale institute to be set up that requires substantial government funding, therefore, funding is an issue of primary concern.

Developing countries that wish to follow the institutional approach of ITRI need not follow Taiwan's system of funding it, however. There are a number of options they could come up with, using combinations of various types of funding, for example through a regional collaborative system, the help of foreign enterprises, or by diverting funds from national universities and research institutes who could work along with the larger one instead.

The main point here is that consolidation of institutes, as would automatically occur through this approach, creates **efficiencies.** Instead of dividing funds into several small doses for a number of institutes conducting similar research, it would be far more advantageous to combine institutes and accord the super-institute a large sum. It is a question of the government's *commitment* to such a system - and to the promotion of its chosen high-technology - that will be the deciding factors in the success of this approach.

LESSONS LEARNED FROM TAIWAN'S EXPERIENCE WITH ITRI

1. SCALE of the institute is important

Institutes are important in bridging gaps between academia and industry, and scale matters very much. ITRI owes its size to the merging of at least 3 institutes at the time of its creation. It has constantly been expanded since then.

Taiwan's SMEs, though agile and flexible, would not have been able to succeed without the research and technical support that ITRI offered them through joint research, technological adaptation and transfer, dissemination of research results in fast-paced tech fields, and incubation services. The SMEs simply did not have the capital and human resources to accomplish all this on their own. ITRI has state-of-the-art equipment, keeps track of latest technologies through international contacts and linkages, and receives half of its funding nearly US$500 million in 2000, from the government. Such a huge organization was a necessity for the Taiwanese industry. The scale was further expanded by situating the Hsinchu Science-based Industrial Park in the vicinity. Similarly, ITRI's new campus in southern Taiwan has been constructed in Tainan, the same locale as the Tainan Science Park, again to create the advantages of scale and proximity of industrial research centers.

2. TIMING is important

Developing countries do not have to retrace all the same steps that industrialized countries took; jumping ahead and cutting in at an advanced stage in the race has worked, for instance, for Taiwan, where the government displayed keen acumen in taking the country in the "right" high-tech direction. One of the factors that is very important in ensuring a successful outcome of being 'state-steered' in high-tech is if the government knows *when* to cut in.

This has been nicely explained by Evans (1986)[31], in his claim that there are "moments of transition" when it may be possible for a Third World country to break into an existing industry. At these moments, "the interests of local capital are still undefined and international capital may be caught off balance" (p. 805). However, he states, taking advantage of such moments requires a pre-existing infrastructure

[31] In Meaney (1994).

and organizational capacities (or, I might add, a quickly-modified one, as in Taiwan's case) and regime commitment to development.

Similarly, with Taiwan facing a different situation today than it did 30 years ago, timing is still important, but in a different and more pressing way. The need for Taiwan to produce higher value-added technological products is immense, and in order to really move ahead, it needs to do fast-paced, cutting-edge research in latest high-tech fields, for example, nano-technology. Since Taiwan's government has decided that Taiwan now needs to be a leading global *innovator*, rather than manufacturer, it needs to jump in at the same time as advanced countries. Hence the strong attention being paid to nanotechnology at ITRI these days.

3. CHOICE OF SECTOR is important

This concept ties in to an extent with the preceding one of timing, in that *when* to make the leap into high-technology depends upon which kid of high-technology is being talked about. However, what is important to emphasize here is that a sector that will work for one country will not necessarily work for another. The academic bent of its work force, the needs of local industry and the local population, and the pre-existing institutional structure (including regional and international research links) are all extremely important considerations in deciding which form of high-tech development to pursue. In the 1970s, for instance, given the rise of global electronic firms, the fact that engineering was a preferred academic discipline in Taiwan, and Taiwan's cheap labor, electronics and IT may have seemed the best option. Given the resource needs of its population, the pursuit of biotechnology may have been the obvious sectoral choice for Kenya today - probably building upon existing agricultural institutional foundations. Deciding which sector to invest in is an important, weighty decision to make, with long-term repercussions.

4. POLITICAL LEADERSHIP is important

Taiwan had strong political leadership backing its drive towards high-tech development. The fact that the government was strong and stable and took active interest in technological development meant that strong decisions could be taken, even if not necessarily favorable with all entities that would be affected. Since government usually plays a strong role in technical development in developing countries - at least in the early stages, it is important that it be able to take a firm stand and persist with its goals. Also, there should be some continuity in its course of action. As was seen in the case of Pakistan, rapidly changing governments with differing priorities have prevented stable high-tech growth from occurring.

6 CONCLUSIONS

This chapter presents the main conclusions of the study, as well as some policy and research implications.

CONCLUSIONS

1) The fact that the Taiwanese government **consolidated** several different research institutions into a single one to create ITRI gave rise to a scale at which R&D could be conducted effectively and efficiently.

2) It has been said by some authors that Taiwan is a striking example of an SME-based country that has managed to achieve high-technological and economic success. This thesis argues that this was possible chiefly because at the core of the country's innovation system lies a large R&D institute.

POLICY IMPLICATIONS

Many developing countries (e.g., Pakistan) have set up a large number of research institutes as a testament to their commitment to S&T research. Often, these are set up on a stand-alone basis (or to report directly to one other higher authority) without a clear idea of how they will inter-link with existing institutes. Often, existing institutes are doing very nearly the same thing, or functions that could easily be carried out by another existing institute. Or they may be doing related research but are so short of funds that they are not fulfilling their intended goals. As such, these institutes are doing little to facilitate R&D and innovation in the country. In fact, by scattering funds so that little can be achieved at any individual institute, they are almost a hindrance rather than a help. This is unfortunate, since institutions are known to play a key role in a country's innovation system, particularly where the gap between industry and academia is large.

Policy Implication No. 1

These institutes need to be merged in order to make the most of available funds and personnel, and to reap economies of scale.

Developing countries today are trying to figure out how they can jump into high technological development in their efforts to catch up with the industrialized world. High-tech development in even a single sector is a long-term, highly capital-intensive process that requires long-term planning, and re-structuring and strengthening of the national innovation system. Also, developments in high-tech tend to occur in sudden spurts that can be quite rapid; the possibility of getting left behind is all too easy. In the case of Taiwan, much deliberation was done before selecting electronics (ICs) for development, and the decision was based on the fact that international and domestic conditions were right at the time. In developing countries, the state usually decides which high technology to pursue (although as development proceeds, its role tends to grow less relative to industry). Regarding the early stages of state intervention, then, the following points are crucial:

Policy Implications No. 2 and No. 3

- *Timing of intervention in a particular technology is important*
- *Choice of sector is important*

Both the above factors depend on a number of factors internal and external to the country.

Also important to note with regard to government interventions is the fact that political leadership can and does play a critical role in determining the success of a plan to move towards developing a particular high-technology. Political leadership certainly was a factor in Taiwan's success. Also, lack of common long-term development goals for Pakistan's various political leaders has been a factor in its lack of development, and that of some other developing countries.

RESEARCH IMPLICATIONS

This study contributes to the larger body of literature on the role of institutions in national innovation systems of developing countries by explaining the need for large-scale research institutes. Large-scale, government-supported institutes have an immense role to play in SME-dominated economies, particularly developing economies. This thesis offers a theory on how Taiwan achieved its technological success despite its predominance of SMEs.

Regarding further research:

- It would be interesting to examine other successful national cases involving large-scale government-supported research institutes, in order to come up with generalized lessons.

- It would be particularly useful to study instances of current developing countries that have tried to do this by consolidation of research institutes, and with what results.

- Further, in-depth study of ITRI itself would also be highly desirable, since this study could not go in much depth into all its various functions and research linkages.

References

Afuah, A. 1998. *Innovation Management: Strategies, Implementation, and Profits.* New York: Oxford University Press.

Ali, S. 2001. *The Right Choices.* Article available online at: http://www.pakprofessionals.com/articles/dr_atta.asp?artcod=25

Amsden, A. H. and Chu, W.-w. 2003. *Beyond Late Development: Taiwan's Upgrading Policies.* Cambridge: MIT Press.

Amsden, A. H. 2001. *The Rise of "The Rest".* New York: Oxford University Press.

ATIP. 1998. *Science and Technology Overview pf Pakistan.* Report available at: http://www.cs.arizona.edu/japan/atip/public/atip.reports.98/atip98.049.html

Barbier, E. and Homer-Dixon, T. 1996. *Resource Scarcity, Institutional Adaptation, and Technical Innovation: Can Poor Countries Attain Endogenous Growth?* New York: American Association for the Advancement of Science.

Bass, H. 1999. Export Dynamics in Taiwan and Mainland China, 1950s-2000: A Schumpeterian Approach. Institute for World Economics and International Management, University of Bremen, Nr. 13, January 1999.

Bell, M. and Pavitt, K.L.R. 1993. Technological accumulation and industrial growth: contrasts between developed and developing countries. *Industrial and Corporate Change* 2: 157-210.

Brooks, H. 1995. What We Know and Do Not Know about Technology Transfer: Linking Knowledge to Action. In *Marshalling Technology for Development*, Proceedings of a symposium organised by the National Research Council and the World Bank, National Academy Press, Washington, DC, pp.83-96.

Buatsi, S. 1988. *Technology Transfer: Nine Case Studies.* London: Intermediate Technology Publications.

Carlsson, B., Jacobsson, S., Holmen, M. and Rickne, A. 2002. Innovation systems: analytical and methodological issues. *Research Policy* 31: 233-245.

Carlsson B. and Stankiewicz, R. 1995. On the Nature. Function and Composition of Technological Systems. *Technological Systems and Economic Performance: the Case of Factory Automation.* B. Carlsson, ed. Dordrecht: Kluwer.

Casper, S. 2000. Institutional adaptiveness, technology policy and the diffusion of new business models: the case of German biotechnology. *Organization Studies* 21: 887-914.

Chang, P.-C., Wang, C.-P., Yuan, B. J.C. and Chuang, K.-T. 2002. Forecast of Development Trends in Taiwan's Machinery Industry. *Technological Forecasting and Social Change* **69**: 781-802.

Chang, P.-L., Hsu, C.-W. and Tsai, C.-T. 1999. A Stage Approach for Industrial Technology Development and Implementation - the Case of Taiwan's Computer Industry. *Technovation* **19**: 233-241.

Choi, H. S. 1986. *Technology Development in Developing Countries.* Tokyo: Asian Productivity Organization.

CIA. 2003. Information on Taiwan available on website available at: http://www.cia.gov/cia/publications/factbook/geos/tw.html

Cooper, C. 1994. Relevance of Innovation Studies to Developing Countries. *Technology and Innovation in the International Economy.* C. Cooper, ed. Hants: Edward Elgar, pp. 1-36.

Daudpota, I. 2000. The National Institute of Information Technology. Available online at: http://www.dareecha.org/NIIT.htm

Davies, I. 1981. Taiwan: The Economic Significance of the Industrialization Programme. *The Australian Journal of Chinese Affairs* 0: 1-20.

Edquist, C. 2001. The Systems of Innovation Approach and Innovation Policy: An Account of the State of the Art. Lead paper presented at the DRUID Conference, Aalborg, June 12-15, 2001, under theme F: *National Systems of Innovation, Institutions, and Public Policies*, Draft of June 1, 2001.

Edquist, C. 1997. Systems of Innovation Approaches - Their Emergence and Characteristics. *Systems of Innovation: technologies, Institutions and Organizations.* C. Edquist, ed. London: Pinter, pp. 1-35.

Edquist C. and Johnson, B. 1997. Institutions and organizations in Systems of Innovation. *Systems of Innovation: technologies, Institutions and Organizations.* C. Edquist, ed. London: Pinter, pp.41-63.

EIU. 2001. *Country Profile 2001: Taiwan.* London: Economist Intelligence Unit.

Freeman, C. 2002. Continental, national and sub-national innovation systems - complementarity and economic growth. *Research Policy* 31: 191-211.

Freeman, C. 1987. *Technology Policy and Economic Performance: Lessons from Japan,* London: Frances Pinter.

Gerschenkron, A. 1963. The early phases of industrialization in Russia. *The economics of take-off into sustained growth.* W.W. Rostow, ed. London: Macmillan.

Gerschenkron, A. 1962. *Economic Backwardness in Historical Perspective.* Cambridge: Harvard University Press.

GIO. 2003. History: Miraculous Economic Transformation. *The Republic of China Yearbook - Taiwan 2002,* available at website of Government Information Office, Republic of China (Taiwan):
http://www.gio.gov.tw/taiwan-website/5-gp/yearbook/chpt04-2.htm#10

Ho, S. 1978. *Economic Development of Taiwan, 1860-1970.* New Haven: Yale University Press.

Ho, S. 1968. Agricultural Transformation Under Colonialism: The Case of Taiwan. *The Journal of Economic History* 28: 313-340.

Hobday, M. 1995. *Innovation in East Asia.* Hants: Edward Elgar.

Hsu, J. 2003. Industrial Technology Research Institute (ITRI). Presentation made on February 20, 2003.

Hung, S-c. 2003. The Taiwanese System of Innovation in the Information Industry. *International Journal of Technology Management* 7: 788-800.

IPS (2002), "Pakistan's Economy and Budget: 2002-2003", *Pakistan Economist,* Issue 27, available online at:
http://www.pakistaneconomist.com/issue2002/issue27/i&e4.htm

ITRI (2003) ITRI website. Homepage is at: http://www.itri.org.tw/

Jacobsen, John K. 2000. *Technical Fouls: Democratic Dilemmas and Technological Change*, Boulder: Westview Press.

Keller, W.W. and Samuels, R.J. 2003. Innovation and Crisis in Asia. MIT Japan Program, Working Paper 02.03.

Khan, S.R. and Iqbal, F.Y. 2000. Climate Protection and Economic Protection in Developing Countries - Pakistan Chapter. Washington, D.C.: National Environmental Trust.

Lall, S. 2000. Technological Change and Industrialization in the Asian Newly Industrializing Economies: Achievements and Challenges. *Technology, Learning, and Innovation: Experiences of Newly Industrializing Economies.* L. Kim and R. R. Nelson, eds. Cambridge: Cambridge University Press, pp. 13-68.

Li, K.-T. 1995. *The Evolution of Policy Behind Taiwan's Development Success.* Singapore: World Scientific.

Lin, O.C.C. 2003. National Innovation System and the Role of National Institute. Presented at the Six Countries Program Conference, June 5-6, 2003. Available at: http://strategis.ic.gc.ca/epic/internet/inscpc-cpsc.nsf/vwapj/Lin_4.ppt/$FILE/Lin_4.ppt

Lin, O.C.C. 1998. Science and Technology Policy and its Influence on Economic Development in Taiwan. *Behind East Asian Growth: the Political and Social Foundations of Prosperity.* H. Rowen, ed. London: Routledge, pp. 185-206.

Liu, X. and White, S. 2001. Comparing Innovation Systems: A Framework and Application to China's Transitional Context. *Research Policy* 30: 1091-1114.

Lundvall, B.-Å. 1992. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning.* London: Pinter.

Matthews, J. 2002. Globalization, Development, and Strategies of Linkage, Leverage and Learning. Presentation given on 11 November 2002 at Macquarie Graduate School of Management, Sydney.

Matthews, J. 2001. The Origins and Dynamics of Taiwan's R&D Consortia. *Research Policy,* 13: 1-20.

Matthews, J. 1999. Innovation: Can Australia Learn from Asia? *Committee for Economic Development of Australia (CEDA).* (Edited highlights of report by the Australian Business Foundation.)

Meaney, C. S. 1994. State Policy and the Development of Taiwan's Semiconductor Industry. *The Role of the State in Taiwan's Development.* J. Aberbach, D. Dollar and K. Sokoloff, eds. Armonk: M.E. Sharpe.

Myers, R. H. and Ching, A. 1964. Agricultural Development In Taiwan Under Colonial Rule. *The Journal of Asian Studies* 23: 555-570.

Mytelka, L. K. 1998. Competition, Innovation and Competitiveness: Learning to Innovate Under Conditions of Dynamic Industrial Change. A paper prepared for the International Conference: *The Economics of Industrial Structure and Innovation Dynamics,* Centro Cultural de Belem, Lisbon, 16-17 October 1998.

Nelson R. 1993. *National Systems of Innovation: A Comparative Study,* Oxford: Oxford University Press.

Perez, C. and Soete, L. 1988. Catching up in technology: entry barriers and windows of opportunity. *Technical Change and Economic Theory.* G. Dosai, ed. New York: Pinter, pp. 458-479.

Porter, M. E. 1990. *The Competitive Advantage of Nations.* London: Macmillan.

Rahman, A. 2003. Personal communication with Pakistan's Federal Minister for Science and Technology on July 29, 2003.

Rahman, A. 2000. The Way Forward. Presentation at the Beaconhouse International Academic Conference, November 8-10, 2000. Available at: http://www.bitsonline.net/tie/atta_article.html

Rizvi, S. A. 2002. The Need to Strengthen R&D Institutions: An Interview with Dr Atta-ur-Rahman, Minister for Science and Technology. *Pakistan Economist* 11. Available online at http://www.pakistaneconomist.com/issue2002/issue11/etc6.htm

Sachs, J. D. and McArthur, J. A. 2002. Technological Advancement and Long-term Economic Growth in Asia. *Technology and the New Economy.* C. Bai and C. Yuen, eds. Cambridge: The MIT Press.

Sachs, J. D. 2002. *Science Serving People* (in foreword). International Atomic Energy Association (IAEA), Technical Cooperation for Development. Brochure available at: http://www-tc.iaea.org/tcweb/publications/Science_Serving_People_with_pictures.pdf

Shih, C. 2002. *Taiwan's Technology Innovation: Strategies and Challenges.* ITRI, presentation at Stanford University, made on Sept. 6, 2002.

Shyu, J. Z. and Chiu, Y.-c. 2002. Innovation Policy for developing Taiwan's competitive advantages. *R&D Management,* **34**(4): 369-374.

Solow, R. 1957. Technical Change and the Aggregate Production Function. *Review of Economics and Statistics* 39 (August): 312-320.

STAP. 1996. *International Industrial Collaboration for accelerated adoption of environmentally sound energy technologies in developing countries.* Science and Technical Advisory Panel (STAP) of the Global Environment Facility). Report of a STAP Workshop, Amsterdam, 7-8 June 1996.

Steinle, C. and Schiele, H. 2002. When do Industries Cluster? A Proposal on how to Assess an Industry's Propensity to Concentrate at a Single Region or Nation. *Research Policy* 31: 849-858.

Stiglitz, J.E. 1987. Learning to Learn, Localized Learning and Technological Progress. *Economic Policy and Technological Development.* P. Dasgupta and P. Stoneman, eds. Cambridge: Cambridge University Press, 125-55.

Timmer, M. 2000. *The Dynamics of Asian Manufacturing: A Comparative Perspective in the Late Twentieth Century.* Cheltenham: Edward Elgar.

Tsai, K.-H. and Wang, J.-C. 2002. An Examination of Taiwan's Innovation Policies and R&D Performance, presented at the International Conference on Science, technology and Innovation: Emerging International Policy Issues, Kennedy School of Government, Harvard University, September 23-24 2002.

UNDP. 2002. *Human Development Report 2002: Deepening Democracy in a Fragmented World.* Report available at: http://hdr.undp.org/reports/global/2002/en/default.cfm van Dijk, M. P. and Sandee, H. 2002. Innovation and small enterprise development in developing countries. *Innovation and Small Enterprises in the Third World.* M. van Dijk and H. Sandee,eds. Cheltenham: Edward Elgar, pp. 1-11.

Viotti, E. B. 2001. National learning systems: A new approach on technical change in late industrializing economies and evidences from the cases of Brazil and South Korea. *Science, Technology and Innovation* Discussion Paper No. 12, Center for International Development, Harvard University, Cambridge.

Whitley, R. 2002. Developing innovative competences: the role of institutional frameworks. *Industrial and Corporate Change,* 11: 497-528.

World Bank. 2002. *Constructing Knowledge Societies: New Challenges for Tertiary Education* (Executive Summary). R. Hopper, ed. Washington, D.C.: World Bank.

WTEC. 1997. http://wtec.org/loyola/nano/e_06.htm

Wu, R.-I. and Tseng, M.-S. 1998. The Development of the Information Industry in Taiwan. *Asia's Development Experiences: How Internationally Competitive National Manufacturing Firms Have Developed in Asia.* T. Kazuo, ed. Tokyo: FASID, pp. 76-124.

Wu, R. -I., Lin, X.-W. and Lin, H.-Y. 2000. Moving from Foreign Technology to Indigenous Innovation: The Case of Taiwan. Draft for publication.

Yeh, W.-A. 2001. The Taiwanese Experience in Retrospect: Before the 1980s. *Taiwan's Economic Success Since 1980.* C. Mai and C. Shih, eds. Cheltenham: Edward Elgar, pp. 3-46.