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工業技術研究院（工研院) 之戰略轉型在臺灣高科技產業發展過程: 制度學習方法

The transformation of strategies of the Industrial Technology Research Institute (ITRI) in the course of Taiwan's high-tech industrial development: an institutional learning approach

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Abstract

This thesis examines the transformations undergone by the Industrial Technology Research Institute (ITRI) during the course of Taiwan's high-tech industrialization since the late 1970s. This study proposes a framework that integrates ITRI's approaches in interacting with high-tech industries on the one hand, with the broad economic and political changes happening in its environment on the other. Using an institutional learning model, the thesis identifies the organizational learning capabilities, which in essence underlines the mechanisms of ITRI's interaction adjustment to the changes. The historical analysis suggests three stages, in the contexts of which the institute undergoes through major organizational transformations. The transitions between the stages are different and embedded in the particular economic and political contexts.

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Acronyms

ASIC	Application-specific integrated circuit
BEL	Biomedical Engineering Research Laboratories
BMEC	Biomedical Engineering Center
CCL	Computer and Communications Laboratories
CD-ROM	Compact disk Read only memory
CEPD	Council for Economic Planning and Development
CIECD	Council for International Economic Cooperation and Development
CMOS	Complementary metal oxide semiconductor
CUSA	Council on US Aid
DCB	Development Center for Biotechnology
DOIT	Department of Industrial Technology
DPP	Democratic Progressive Party
DRAM	Dynamic random access memory
EMRL	Energy and Mining Research Laboratories
EPZ	Export-Based Zone
ERSO	Electronic Industrial Research Center
HDD	Hard disk drivers
HSIP	Hsinchu Science-Based Industrial Park
IC	Integrated circuit
ICT	Information and communications technology
IDC	Industrial Development Commission
III	Institute for Information Industry
IPR	Intellectual property rights
ITRI	Industrial Technology Research Institute
KMT	Kuomintang Party
LCD	Liquid display crystal
MED	Medical Electronics and Device Technology Center
MIRI	Metal Industrial Research Institute
MIRL	Mechanical Industry Research Laboratories

MNC	Multinational corporation
MOEA	Ministry of Economic Affairs
MRL	Material Research Laboratories
MRSO	Mining Research and Service Organization
NDC	National Development Council
NIS	National Innovation System
NSC	National Science Council
OBM	Original brand manufacture
ODM	Original design manufacture
OEM	Original equipment manufacture
OESL	Optoelectronics and System Laboratories
PC	Personal computer
PRI	Public research institute
RCA	Radio Corporation of America
SBIR	Small Business Innovation Research
SME	Small- and medium-sized enterprise
STAG	Science and Technology Advisory Group
TAC	Technical Advisory Committee
TI	Texas Instruments
TSMC	Taiwan Semiconductor Manufacturing Corporation
UCL	Union Chemical Laboratories
UIRL	Union Industrial Research Laboratory
UMC	United Microelectronics Corporation
VLSI	Very-large-scale integration

1 Introduction

1.1 Background

The 2016 presidential election campaign in Taiwan brought back on the political agenda a discourse on future directions of the national economic development. In a quite notable change from the past, the focus of the campaign was shifted from the politically sensitive questions of Taiwan's sovereignty to economic issues. Certainly, Taiwan's manufacturing sector faces multiple challenges in intensifying worldwide competition that undermines the nation's economic prospects. To answer the challenges, president-elect Tsai Ing-wen named five major targets – green energy, biotechnology, national defense, smart machinery and the Internet of Things – as the incoming government priorities to raise competitiveness of the local industry and therefore to revive economic momentum.[1] In this perspective, a study on the course of the island's high-tech industrial development seems necessary for a comprehensive understanding of the institutional framework and legacy of the ongoing "developmental" efforts of the government.

This thesis seeks to assess strategic roles played by the Industrial Technology Research Institute (ITRI) in the process of the high-tech industrial development in Taiwan. As a leading public research institute (PRI) of the country, the Institute has acted as a critical agent in fostering technology upgrade of the local industry. ITRI's interactions with the state, on the one hand, and the business sector, on the other, have been the most important aspect in broad national efforts to develop Taiwan's semiconductor industry, which has subsequently driven the growth of Taiwan's capabilities in computers, lighting, displays, telecommunications, photovoltaics, and machinery.

ITRI can be categorized as the country-level laboratory. It is the main executive arm of the Ministry of Economic Affairs in its industrial technology promotion initiatives,

[1] *Taipei Times, April 6, 2016*

undertaking several billion dollars' worth of projects annually. Compared with most other countries' national laboratories, which are focused more on basic and academic research, ITRI's position is quite special, since it has always been intended to perform applied research.

ITRI's mission historically has included five major elements: (1) to engage in applied research with emphasis on industrial efficiency and to rapidly improve industrial technology; (2) to develop flexible, commercial and advanced technology; (3) to diffuse the research results and technology to the industry; (4) in compliance with government policy, to assist SMEs to upgrade their technology; and (5) to cultivate industrial technology specialists.[2]

Determining how to properly integrate a PRI as technology powerhouses to aid industry is an important issue for policy makers and public research management in many countries as PRI's impacts on industrial development are dynamic and complex, and can be generated through some sequential stages stemming from R&D output, technology transfer and commercialization.[3] Since industries co-evolve with their environments, where new demands and technologies are emerging in an increasingly uncertain manner, R&D institutes need to continuously restructure and change their strategies to correspond to the industry environments.[4] Finding new ways to serve industrial demands may also require new R&D strategic management paradigms. Consequently, the organizational structure of the research institutes should undergo a dynamic and ongoing reformation in order to satisfy contemporary knowledge demands.[5] Understanding the dynamism behind the evolutionary phenomenon and gaining insights to facilitate future decisions are important and challenging issues.

In this connection, there is a common agreement that ITRI is a successful case of the government-led technology learning for emerging technology-intensive industries.

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[2] *Huang, p.31*
[3] *Shih, p.7*
[4] *Arnold et al., p.4*
[5] *Simpson, p.17*

ITRI is considered to be an instrument for both the government (as an mediating agency to implement the state policy in high-tech development) and private sector (to upgrade its technological capacity and attain an access to the global flow of technology). For example, Breznitz describes ITRI as a product of division of labor between the state and business, where ITRI under the guidance of the Ministry of Economic Affairs makes decisions about which technologies industry should acquire, subsequently does most of research and development up to the level of a working prototype, and then diffuses the results to industry, which concentrates on final development and integrated design. Therefore, it was this division of labor that became a springboard for Taiwanese high-tech companies to attain a very competitive position in the global IT production.[6]

Since its foundation in 1973, ITRI has made appropriate and timely adjustments to its developmental emphases and strategies, in order to achieve accelerating improvement of industrial technology, help in establishing newly emergent technology industries, upgrade traditional ones, and in general enhance industrial competitiveness .[7]

It remains unclear, however, what are the sources of these transformations. Therefore, the main goal of this study is to trace the nature and dynamics of the transformations that ITRI has undergone in its interaction with the evolving high-tech sector of Taiwan in the context of technology promotion policies implementing by the state.

1.2 Theoretical context

Traditionally, roles and functions of PRIs in economic development has been commonly examined from the analytic perspective of innovation systems. In contemporary policymaking innovation systems approaches in general have provided rationales for enhancing public science, which is seen central to supporting social needs, generating knowledge to back domestic industrial competitiveness and providing advanced scientific training. The analytical focus under this approach is on an interactive ecology of elements and actors: economic performance of a country

[6] *Breznitz, p.155*
[7] *Hsu and Chiang, p.127*

depends to a large extent on how actors relate to each other as elements of a collective system of knowledge creation and use. [8]

The innovation systems approach was advanced in the late 1980s when Freeman proposed the concept of *national innovation systems (NIS)* in his study of Japan's technology development, defining it as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies within national borders.[9] Subsequent approaches to studying NIS split between focusing on either the institutions supporting innovation or on the relationships between institution of public and private sectors.

PRIs have always been considered important components of a NIS due to their role in creating, discovering, using and diffusing knowledge. Crow and Bozeman highlighted that PRIs can be "focused on the production of public knowledge, or they can be designed to produce knowledge for the consumption of a single firm, sector or industry".[10] The emphasis on knowledge puts PRIs in an important position within economies – knowledge creation and application are crucial for spurring productivity, economic growth and employment. Knowledge is a source of future and sustained growth that cannot be exhausted and is often non-rival. Unlike any other factor of production, knowledge can be used by many firms and countries at the same time to foster sustainable economic growth.[11]

Lente *et al.* consider PRIs as a new type of intermediary organization that functions at a system or network level, in contrast to traditional intermediary organizations that operate mainly bilaterally. These "systemic intermediaries" are important for long-term and complex changes, such as the transition to sustainable development, that require more systemic efforts to articulate needs and options, the alignment of relevant actors and the support of learning processes.[12] Dodgson and Bessant propose that PRIs can perform particular activities bridging the demand (user needs) and the

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[8] *OECD (2007), p.9*
[9] *Ebner, p.109*
[10] *Crow and Bozeman, p.24*
[11] *OECD (2011), p.20*
[12] *Lente et al., p.265*

supply side (resources) in innovation processes, such as articulation of specific needs and bridging links with outside knowledge system. As nature of innovation is more open today, roles of PRIs in linking various actors such as users, producers, and other stakeholders can be expected even more. In short, PRIs can help to solve "systemic failures" that might slow down or even block interactive learning in innovation systems.[13]

Consequently, PRIs have become more tightly linked to other entities in the innovation system, playing an important role in their performance. There is increased inter-organizational collaboration and exchange, as well as a growing application of scientific research in industry and society. This has occurred as scientific disciplines have converged, computing advances have increased opportunities for knowledge "hybridization", and international communication capacity has diffused methods and results.[14] PRIs also have major impacts on universities, acting as an intermediary between firms and universities, by interpreting the technical needs of firm and passing this information to universities, and provide skilled labor for firms. These roles and functions are often highly interdependent.[15]

Concerning PRIs' success factors, Rush *et al.* studied eight PRIs in eight countries, both developed and newly industrialized. The success factors can be classified as internal (under direct control of PRIs), external (outside of PRIs' control), and negotiated (affected to a lesser or greater extent by PRIs):

- *Internal factors*: leadership, defined strategy, flexible structure, training, technical competence, project management, personnel management, good communications, technology search;
- *External factors*: stable policy, consistent funding, demanding users, government commitment, macro-economic growth, industrial development;

[13] *Dodgson and Bessant, p.57*
[14] *Geuna et al., p.394*
[15] *Nedrum and Guldbrandsen, p.331*

- *Negotiated factors*: industrial input, market responsiveness, networking, learning from firms, links to policy making, links to universities and image and awareness.[16]

Country-level studies conducted in Europe have shown how PRIs support innovation. An analysis of industrial research institutes in Sweden found that they assisted companies to move "one step beyond" their existing capabilities and reduced the risks associated with innovation.[17] In the United Kingdom, entities in the intermediate research and technology sectors were considered to provide "one-to-many" channels for spreading innovation to business and industry and to generate R&D spillovers for the economy.[18] Firms gained access to a network of organizations and a wider range of research than would be possible in-house, and in many instances the sector offered resources on a cost- and risk-sharing, industry-wide, basis. Analyzing Norwegian data, Nedrum and Guldbrandsen highlighted a number of motives for firms to purchase R&D from PRIs, such as to increase inadequate in-house knowledge and skills, to access equipment or test facilities and to boost in-house capacity, particularly during busy periods. The firms revealed that this R&D was important for developing new or improved processes and products, work methods and tools, production quality and reliability and identifying user needs and markets.[19]

However, roles of PRIs in late developing countries are different. For example, in Korea, the majority of the industry sectors are huge corporations, which are capable of conducting world-class R&D and accessing international technology sources, hence PRIs have been traditionally passive.[20] In Singapore, the mainstream industry is multinational companies, so the innovation system is similar to the leading countries.[21] In Taiwan, more than 97 percent of firms are small and medium-sized enterprises. Whereas managerial and production flexibility of the companies is ensured, the scarcity of financial resources and the companies' low ability for

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[16] *Rush et al., p.25*
[17] *Arnold et al., p.93*
[18] *Oxford Economics, p.11*
[19] *Nedrum and Guldbrandsen, p.335*
[20] *Lee, Bae, and Lee, p.423*
[21] *Lee and Win, p.439*

technological modernization undermined their capacity to compete on the world market. Therefore PRIs in Taiwan have played a more dominant role.[22]

Table 1-2-1. Roles and tasks of ITRI in Taiwan's high-tech development

ITRI's roles	*Industry*	*Tasks*
Strategic	Semiconductors; mechanical	Spin-offs (initiator): spin-offs as flagships and new models of entrepreneurship to initiate development of new industries
Facilitating	Laptop PC; electric scooters	R&D alliances (coordinator): through integrating interactions of local firms into joint R&D to speed up technological diffusion, reduce risks, and enhance technological capabilities
	Biotechnology; nanotechnology	Technology incubation (incubator): assisting new entrepreneurs with an environment for research and raising initial investments:
Technical support	CD/DVD-ROM; bicycle, golf ball and tennis racket	Technology transfer (technical partner): licensing of key components and technologies to local firms
	Machine tools; motorcycles; textile, chemical	Contract services (R&D agent): new product development, process improvement, technology consulting
	All	Technical services (technical assistance): testing, certification, calibration, training, technical information

Source: Jan and Chen, 2006

More specifically, Jan and Chen summarized ITRI's roles in the Taiwanese innovation systems as a strategic pioneer to create new industries, a technical

[22] *Castells, p.216*

supporter to upgrade industry technologies and a facilitator to forge industrial synergies.[23] As it is shown in Table 1-2-1, ITRI has developed corresponding models to interact with different industries: spin-off and incubator, contract and technical services, industrial consortia and licensing.

In a similar way, Chang, Hsu and Tsai point out at three approaches used by ITRI to support the industrial upgrading process:

- Diffusing mature technology to local firms and facilitating their commercialization in the early phase of catching-up;
- Reinforcing the industrial R&D system and accelerating R&D efficiency for local industries in order to capture market opportunities;
- Defining the technological requirements to help local industries develop advanced technologies.[24]

Noble in a study of Taiwan's technology policy in relation to hard disk drivers (HDDs) and CD-ROMs proposes an "ITRI model", which combines development initiative and engineering support from the quasi-governmental ITRI by a mass of small to medium-sized firms in the adjacent Hsinchu Science-Based Industrial Park (HSIP).[25] Under this configuration, the Taiwan's government provides technological support for both long-term development and specific innovative products.

There are two conclusions that can be drawn from the innovation systems research streams in regard to the ITRI's involvement in the course of Taiwan's high-tech development. The first is that ITRI has played an important role in facilitating technological capabilities and formation of the domestic high-tech industries. At the firm level, there has been some strategic or performance related benefits to participating in collaboration with ITRI. Nationally, it has been expecting spillover effects as result of the collaboration, along with improvements in national

[23] *Jan and Chen, p.564*
[24] *Chang, Hsu, and Tsai, p.235*
[25] *Noble (2000), p.3*

competitiveness. The second conclusion is that the ITRI's involvement to much extent has been politically driven and conditioned.

However, in order to understand the transformations undergone by ITRI in its interaction with the external environment, it is not enough to simply investigate the components of Taiwan's NIS. Rather, it is the changes in the interactions between the components that must be examined as different phases of technology expertise require different development strategies and policies. This remark challenges explanatory power of the concept of innovation systems that tends to focus on structure not on mapping of dynamics. Patel and Pavitt argue that most national innovation system research is static, and much work in the area remains concerned with describing patterns of expenditure, and the creation of new institutions and policies, rather than in-depth analysis of why and how changes occur.[26] Therefore the innovation systems approach needs to be adjusted and refined in order to show not what the best policy or strategy is, but how a system can adapt itself in terms of policy and institutions.

A possible direction in this perspective can be found in the institutional learning model developed by Yu in an attempt to combine innovation systems with evolutionary changes. Following Dahmen's "development blocs" framework and Mathews' concept of "economic learning", Yu argues that institutional dynamics can be explained by "institutional learning" processes that happen at two levels: "leaning-how-to-learn" and "learning-how-to-change". "Learning-how-to-learn" refers to the institutionalization of past learning experiences to guide new technical learning. Technical learning experiences, succeeding or failing, are summarized and memorized as institutional structures, routines, or codified documentations. These institutional memories are then applied to learning of new technologies or industries.[27] And the new experiences, whether they succeed or fail, are summarized and used to refine the institutional memories of how to learn. This loop of "learning-how-to-learn" leads to more and more efficient learning practices of innovation

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[26] *Patel and Pavitt, p.93*
[27] *Yu, p.66*

systems as long as the fundamental structures and interactions of the innovation systems are effective.

However, when significant internal or external changes happen, for instance, a new technological paradigm emerges and wipes out the competitive advantages that a system had built under the old techno-economic paradigm, the institutional memories that have worked before cannot deal with the new changes well. This would very likely be reflected as system crises and both the fundamental institutional structures and interactions and the perceptions of what they should be have to be changed. A new set of routines of "learning-how-to-learn" will need to be developed through the second order of institutional learning – "learning-how-to-change".[28] The latter implies that the system and institutions adjust the institutionalized routines of learning-how-to-learn to resolve the system crises. Memories of handling crises can also be institutionalized ("memorized") as institutional structures, routines, or codified documentations. As in case of learning-how-to-learn, these institutional memories again can be recalled ad applied when a new crisis emerges. It is worth noting that both learning-how-to-learn and learning-how-to-change can leverage either the prior experience of the same country or the experiences of a foreign country.

Furthermore, to much extent "learning-how-to-learn" and "learning-how-to-change" are contradictory to each other. "Learning-how-to-learn" holds the perception that the current institutional structures and interactions are appropriate and reinforces them by improving the efficiency of the system through a learning loop. In contrast, "learning-how-to-change" assumes that the current institutional structures and interactions are old-fashioned and replaces them with new institutional settings by applying and refining institutional memories of institutional change learned before.[29] Therefore by identifying practices in "learning-how-to-learn" and "learning-how-to-change", the transformation of institutional changes and NIS dynamics can be better understood.

[28] *Yu, p.67*
[29] *Yu, p.67*

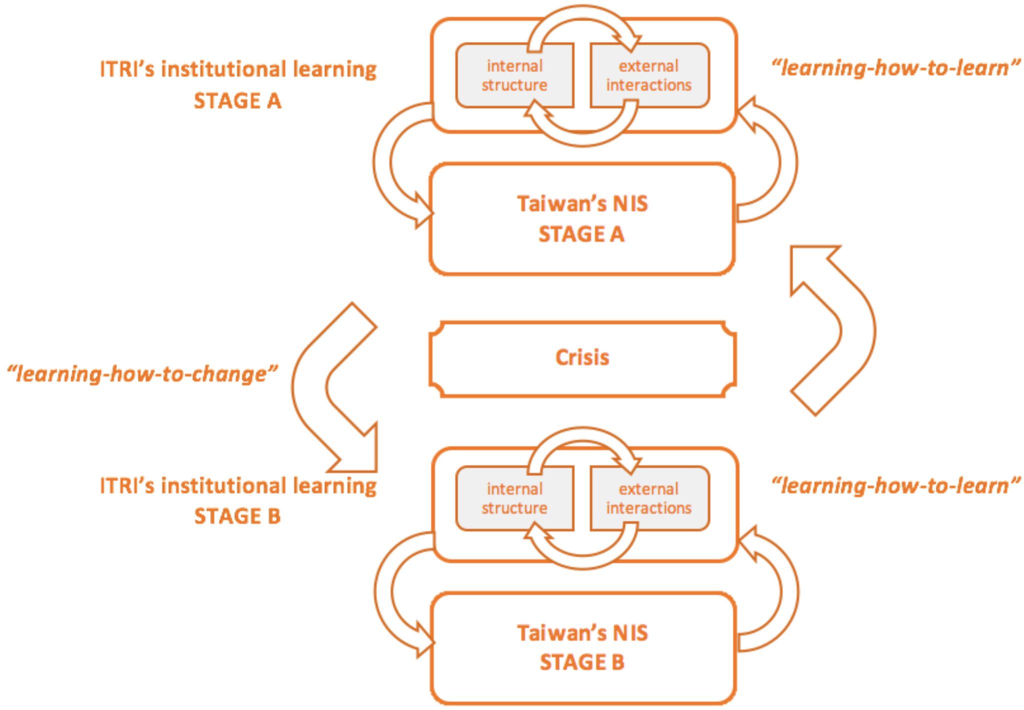
1.3 Model development and methodology

Based on the model of two-level institutional learning and the concept of NIS this thesis argues that the transformation of ITRI's involvement in facilitating technological capabilities and formation of the domestic high-tech industrial sector rests on a co-evolutionary process. The process should be modelled as an evolving system of interacting organizations and institutions that deploys resources and structures of knowledge and capabilities to produce new knowledge and capabilities that then drive economic development of the high-tech sector. In this sense ITRI has both internal and external structures, which are interrelated. The internal structure (i.e., organizational structure) is built upon its innovation capabilities and resource allocations designed to fulfill its technology facilitating function. The external structure is built upon its interaction with the other agents of the NIS. Thus, ITRI continually engages in problem-solving resulting in the construction and maintenance of its capabilities ("learning-how-to-learn"), whereas once facing an external challenge (e.g., raising technological sophistication of local high-tech companies), it would adopt its internal and external structures in order to correspond to the new environment ("learning-how-to-change"). Figure 1-3-1 illustrates the proposed conceptual framework.

The transformations undergone by ITRI in response to external challenges are arguably reflected in major restructures undergone by its research units (Figure 1-3-2), i.e. "leaning-how-to-change" capability. Therefore, based on the units restructuring process, three major transformations of ITRI can be proposed, with the first one taking place at the turning of the 1980s, the second at the turning of the 1990s, and the final one during the 2000s.

However, questions remain about the nature of transformation. A good empirical method to answer such questions is the "collective case study" approach focusing on multiple evolving elements and relationships to understand the complexities and dynamics of the case. This method is well suited to investigating new processes, and has value in understanding how things evolve over time and why they evolve in

Figure 1-3-1. Model of ITRI's two-level institutional learning in the course of Taiwan's high-tech industrial development



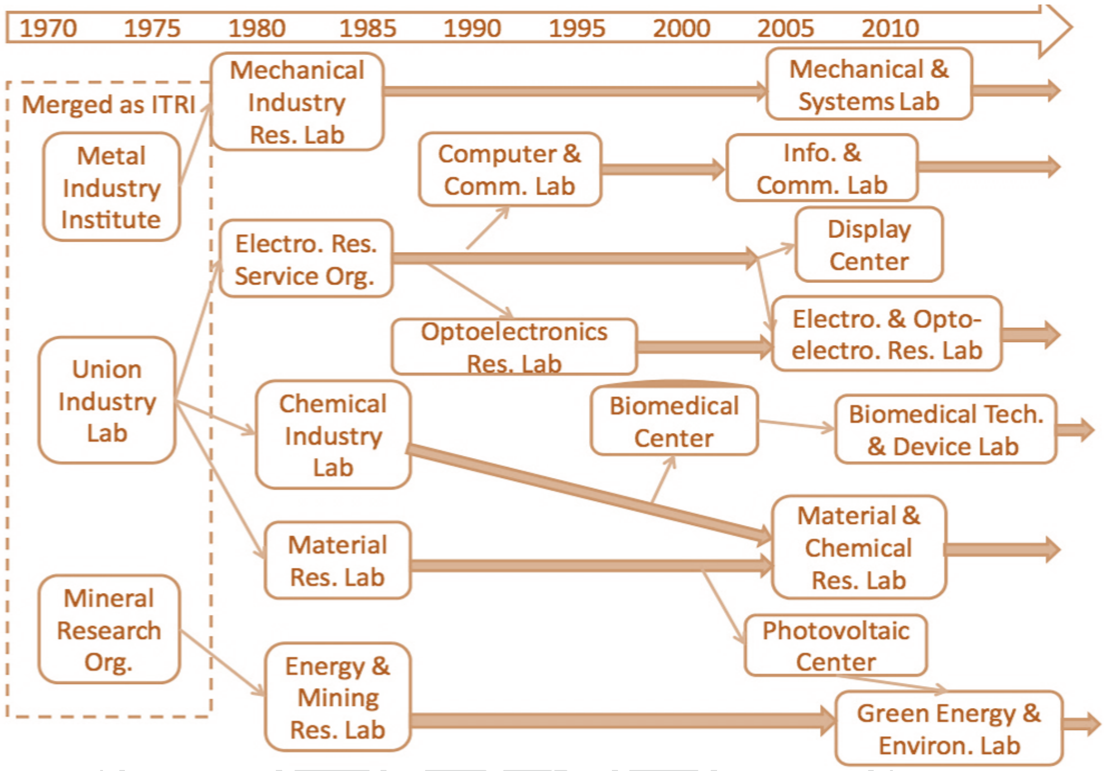
Source: Developed by the author

particular ways. [30] The final outcome of the process analysis will be a narrative (storyline) of how ITRI's interactions within Taiwan's NIS have changed over time in connection to its institutional learning capacity. In the narrative the focus is on extracting impacts of the major changes on ITRI's strategies of interaction.

The thesis will be principally based on a broad secondary literature survey synthesizing different areas such as political economy, organizational management, and history; and it draws on analysis of policy, industry and academic documents. The source base will include official policy documents, white papers, articles from academic journals, media coverage, industry reports, and statistical material.

[30] *Dodgson et al., p.433*

Figure 1-3-2. The restructuring process of ITRI's major laboratories since its establishment



Source: Chen and Chen, 2016

The remainder of the thesis presents the results of the process analysis on the transformation of ITRI's strategies in the course of high-tech industrial development in Taiwan:

• Chapter 2 provides a description of ITRI's background, beginning with an overview of the industrial and political environment prior to ITRI's establishment. It then presents historical roots of the would-be-developed ITRI model and the initial years of ITRI's operation after its foundation;

• Chapters 2, 3 and 4 present findings from the three stages of major transformations of ITRI's engagement with Taiwan's high-tech development process. Each chapter starts with an overview of industrial and political landscape at the particular stage. ITRI's institutional learning strategy is given next, following by case specific analysis.

• Chapter 5 provides analyses of future prospects of the ITRI model in the context of major challenges facing Taiwan's high-tech sector faces at the present time;

• The thesis concludes with a discussion on the implications of utilizing the institutional learning approach to analyze ITRI's performance in the high-tech development of Taiwan.

2 Economic and political background of ITRI

2.1 Industrial and political landscape prior to the 1970s

It is important to understand the model of Taiwan's high-tech industrial development as a logical expansion of and extension from the country's previous development sequences, rather than a detached new undertaking. From the system evolution perspectives, the roots of the model grew out of the consumer electronics manufacturing that saw its formation during the 1950-1960s. Politically this period was characterized with the authoritarian KMT regime, whereas the local society was weak and divided under Martial Law. The government lacked legitimacy among the people as in essence it was a foreign regime migrating from the Chinese mainland. As a means to buttress regime legitimacy and the country's security from threats of the Communist China, the priority of economic development became a consensus among political elite. The pursuit of high growth was balanced by the concern over social stratification and class antagonism – the prime reasons for the downfall of the KMT government on the mainland. Thus, it can be argued that developmentalism was dictated on the regime. [31]

The institutional framework for the governmental developmental efforts was established gradually through a succession of economic reforms and public investments. Land reform in the early 1950s enabled former landowners to cash in their stocks in state-owned enterprises and shift their investment from agriculture to the industrial sector. To further promote industrial self-sufficiency, the government in 1953 adopted a policy of labor-intensive import substitution through multi-year development plans and using a combination of trade and exchange rate policies to encourage domestic industries to produce consumer goods.[32] The impact of the policy was a dynamic growth of industrial output in selected industries (textiles, apparel, wood and leather products, and bicycles) during the 1950s. Import substitution is estimated to have created as much as one-third of industrial growth between 1955 and

[31] *Wu, p.980*
[32] *Wessner, p.314*

1960.[33] However, due to the small size of the domestic market and the relative small size of individual manufacturers, the first wave of the substitution policy translated into limited effects on the general economy and soon reached its limit.

In 1958 the government in Taiwan started implementing an export expansion policy instead and by 1962 adopted several important measures aimed at promoting exports, investment, and industrialization in general. Among the measures, the Nineteen-Point Program of Economic and Financial Reform of 1959 had the most far-reaching effect and laid the foundation for Taiwan's "miracle" takeoff in the 1960s. The program addressed virtually every component of economic, fiscal, and trade policies with objectives to promote private sector development by improving the investment climate, liberalizing administrative control, and strengthening export promotion efforts.[34] The catalytic impact of the program was further enhanced with the adoption of the Statute for the Encouragement of Investment in 1960, which authorized tax, fiscal and duty drawback incentives to attract both local and foreign investment into the manufacturing sector.[35] The start of Export-Processing Zones (EPZs) in 1965 provided a major platform for export-oriented, labor-intensive industrial manufacturing.

The outcome of these measures was impressive. The economic growth during 1963-1972 was at an average annual rate of 11 percent, while exports grew at a rate of 28 percent. The export expansion was accompanied by a dramatic change in the structure of production as industry became the dominant sector of the economy. Textile and plastic goods, along with other light industry products, replaced rice, sugar, and other agricultural products to become the majority of exports. Furthermore, reflecting growing private sector participation in the economy, private industry's share of total manufacturing output rose from 53 percent in 1958 to 86 percent in 1972.[36]

Beyond the economic growth, the impact of the export expansion policies conferred several positive externalities. Internationally, the period saw major electronics firms

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[33] *Dahlman and Sananikone, p.96*
[34] *Ibid., p.98*
[35] *Wessner, p.314*
[36] *Dahlman and Sananikone, p.100*

from US, Europe, and Japan looking to invest in low-cost manufacturing operations in East Asia. Taiwan's export expansion policy opened the way to considerable investment by the firms to transfer the production of discrete components, test and assembly of chips.[37] After Fairchild, one of the leading US chip maker, began to open up pioneering operations overseas, Texas Instruments, General Instruments, and Radio Corporation of America (RCA) in turn established their own packaging and testing factories in Taiwan at the start of the 1960s. Europe's largest chip maker, Philips, followed the trend and voted for Taiwan when it set up and IC packaging line in Kaohsiung.[38]

The central government aggressively sought to facilitate joint ventures and technical agreements between the foreign corporations and local privately owned suppliers of components to them.[39] In 1966 the government published a plan to turn Taiwan into an "electronics industry center". The planning agency – Council for International Economic Cooperation and Development (CIECD) – formed an electronics working group to assist in marketing, coordinating production with the demands of foreign buyers, procuring raw materials, training personnel, improving quality, and speeding up bureaucratic approval procedures. This created linkage effects through technology and skill transfer in various sectors of Taiwanese industry, leading to use more advanced technology and dramatic improvements in the quality of local production and management.[40] Therefore, the period marked the integration of Taiwan's electronics components manufacturing into the world-wide production chain.

The measures were very successful: by 1968 the electrical and electronic goods industry was the second biggest exporter after textiles with a rate of growth at 58 percent a year between 1966-1971.[41] However, soon it became apparent that the foreign corporations had no intention of locating any higher-skilled operations in Taiwan, leaving local producers to obsolete technologies. The sustainability of this first success in advanced electronics production, therefore, relied on relative low

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[37] Mathews and Cho, p.163
[38] Cheng, B-S., p.10
[39] Wade, pp.93-94
[40] Dahlman and Sananikone, p.101
[41] Wade, pp.93, 95

wages – once the cost advantage of cheap labor vanished, the big corporations would have to relocate their production sites. To some extent these overseas investments represented an opportunistic attitude; on the other hand, Taiwan's local companies were mostly small-scale, and could engage only in manufacturing packaging cases as original equipment manufacturers (OEMs), not to mention the innovation and creativity required to develop high technology. Even though some investors (such as Fine Products Microelectronics Corporation) were exceedingly courageous in trying to do so, they ended in failure after only a brief trial period. [42]

Therefore, the government faced a fundamental conflict in between low technological capacity of local manufacturers and the predominance of small- and medium-sized enterprises (SMEs) in the organizational structure of the domestic economy (from 1961 to 1988, the ratio of the number of SMEs to total number of enterprises was over 97 percent in every single year[43]). Hence, the economic policymakers had to find a niche for Taiwan's small firms in electonics industry dominated by large firms from the leading industrial countries. Given the lack of large-scale funding from public and private sources, the policymakers focused on building a technology promotional platform that would compensate for the lack of endeavors by the private sector.[44]

In this perspective, the creation of ITRI could be seen as a logical institutional choice for the technology learning of the emerging technology-intensive industries in Taiwan. However, it does not follow that the choice was determined or guaranteed by the policymakers. In fact, as it is shown below, the formation of the ITRI model was preceded by an intense political considerations among the state technocrats.

2.2 Institutional roots of ITRI

It must be noted that the emphasis on technology development at the start of the 1970s was neither new nor sudden. In fact, the government had made a priority of industrial technology development starting in 1959 when it established the National Long-term Science and Technology Development Committee (which in 1967 would

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[42] *Cheng, B-S, p.12*
[43] *Kwong, p.60*
[44] *Fuller, p.4*

be reorganized into National Science Council, NSC). Operating under the direct supervision of the prime minister, the Committee was responsible for formulating national science and technology development plans, which were integrated into the four-year economic plans. However, as Megan Greene points out, the science and technology policies in 1960s were neither sophisticated nor detailed enough to play much of a role in the kind of economic transformations that the planners hoped for.[45]

Nevertheless, the period saw a crystallization of a distinctive state approach to industrial technological development, namely the establishment of supraministerial and independent or semi-independent organs to implement specific aspects of economic policy. Their financial and bureaucratic autonomy gave them the authority to bypass many bureaucratic bottlenecks and carry out policies quickly and effectively without much resistance from the rest of the civilian administration.[46] One such key agency is the Council on US Aid (CUSA), which was established in 1948 to administer US aid to the Nationalist government on mainland China. CUSA was one of the first institutions created under the Marshall Plan principle, which required the establishment of a host-country counterpart to the local US aid mission. Organizationally, the Council operated as a semiautonomous entity, a status that greatly enhanced its ability to act decisively in coordinating development policies.[47] CUSA was reorganized several times through the years and during 1977-2014 was the Council for Economic Planning and Development (CEPD). The latter was dissolved and absorbed in 2014 by the newly formed National Development Council (NDC), which lost to much extent the semiautonomous status of its predecessors and is now a governmental branch of the Executive Yuan.

Another example is the Industrial Development Commission (IDC, 1953-1958) of the Economic Stabilization Board.[48] It operated outside the regular machinery of line

[45] *Greene, p.117*
[46] *Wade, p.196*
[47] *Dahlman and Sananikone, p.112*
[48] *IDC was reorganized several times and later would become the Industrial Development Bureau (IDB), the key government agency in industrial development policy and one of the main division of the Ministry of Economic Affairs (MOEA)*

ministries and in an independent manner.[49] IDC actively searched for suitable entrepreneurs to adopt designated technologies, and matched these entrepreneurs with public funding or US aid funding. It dealt directly with issues of what industries should be created. Yet the Industrial Development Commission neither exercised an R&D function, nor diffused manpower to the private sector. However, it was very active in providing protection through import and foreign exchange controls, and in picking winners at both the industry and firm levels, consistently functioning with a high degree of coherence and effectiveness.[50]

The coherence in general was a distinctive feature of the Taiwan's policymaking over the period. During the first three decades of the country's postwar development, economic policy was dominated by a small group of technocrats (of mostly engineering and science background) with a strong orientation toward practical results. Often they had overlapping and sequential memberships between the cabinet and other key economic agencies within the state. This overlap contributed to removing unnecessary administration barriers and greater coherence in policy formulation and implementation.

However, politically the group kept a cleavage between the public and private sectors. Partly this can be explained by the regime's resolve not be beholden to private influence. In contrast to Japan and South Korea, the regime never encouraged creation of big private business groups, seeing in them a potential competitor that could possibly weaken the authority of the government and threaten the state's ability to implement policies in a right manner. Besides, the state apparatus in fact had an exogenous status – it was a group of "mainlanders" and thus it did not have a particular close historical or social ties with the "original" islander population. Yet the political elite tried to assimilated it into the regime by essentially incorporating Taiwanese into the economic realm, first, through the Land Reform of the 1950s, and second, through the export promotion policies of the 1960s.[51]

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[49] *Dahlman and Sananikone, pp.112-113*
[50] *Yu, p.96.*
[51] *Dahlman and Sananikone, p.116*

Therefore, the weak public-private sector relations made bargaining with the private groups particularly difficult, and as a result the government had to rely primarily on the network of state enterprises and public research and service organizations to guide technological upgrading policy. Naturally, local universities might have provided a springboard for the technological takeoff – for example, National Chiao Tung University (NCTU), a preeminent engineering school that produced the country's first integrated circuit in 1966. But they were primarily considered as a source of educating qualified engineers, and not as a suitable environment for producing commercial technologies.[52]

By the late 1970s the Council for International Economic Cooperation and Development (a reincarnation of CUSA during 1963-1973) put under discussion first plans for state-sponsored industrially oriented R&D activities. The plans intended to construct a science park in Hsinchu and to develop the Union Industrial Research Laboratory (UIRL), a small, state-sponsored research institute that had been conducting small-scale industrial research since the early 1960s, into a large-scale R&D center. However, there was no immediate movement on the plans: UIRL was not given a greater role until it was subsumed under ITRI, while the implementation of the park did not begin until 1979.[53]

2.3 Foundation and initial years of ITRI (1973-the late 1970s)

The creation of ITRI was the brainchild of Yun-Xuan Sun, then Minister of Economic Affairs and a member of the elite group of technocrats. The institute was modeled on the Korean Institute of Science and Technology (which in turn had been modelled closely of the Japan's Agency for Science and Technology), which Minister Sun visited in the early 1970s. Thus the patterns of East Asian technology industrialization were diffused and disseminated. In articulating and formulating this strategic plan, Sun insisted that ITRI would have to be a nongovernmental organization (NGO) so as not to be restricted by the bureaucratic apparatus. As such, like its Korean

[52] *Mina, p.17.; Tzeng, p.112*
[53] *Greene, p.117*

counterpart, it could lure overseas Chinese engineers back home by offering salaries two or three times higher than those of civil servants.[54]

However, it was not as easy to establish an NGO utilizing the government's budget as Minister Sun thought. Most legislators did agree with Sun's idea of creating an R&D institute, but they did not support the nongovernmental status of it. Although his proposal confronted a massive opposition in the Legislative Yuan, Sun continued to patiently negotiate and communicate with legislators for about a year until the project was finally approved. In 1973, with NTD 1 million (USD 28,000) from the government, ITRI was created in Hsinchu as a "*cai tuan fa ren*" ("a foundation constituted as a juristic person") with a very clear objective – to support technological upgrading of Taiwan's industries.[55]

Upon the establishment of ITRI, three existing R&D institutions were merged under its aegis: the above mentioned UIRL, Mining Research and Service Organization (MRSO), and Metal Industrial Research Institute (MIRI). This original research composition, however, suggests that initially the government considered ITRI as a main source of industrial technologies for the state's development activities in heavy industries and major infrastructural projects (as a means of revitalizing the economy the government in 1973 launched Ten Major Developmental Projects – six infrastructure projects, three heavy and petrochemical industries and the construction of nuclear power plants – to remove bottlenecks to industrial upgrading). An "electronic" component of ITRI would be set up a year after the institute's creation and would have deep American roots.

In August 1974 Minister Sun met his friend Dr. Wen-Yuan Pan, a Chinese-American engineer working at RCA's David Sarnoff Laboratories in Princeton, New Jersey. The two agreed on a plan to formulate an S&T industrial policy geared toward the creation of a semiconductor industry in Taiwan. Pan subsequently established a group of mostly Chinese-American engineers working for leading American semiconductor companies in the United States. The group regularly convened at Princeton as the

[54] *Tzeng, p.3.*
[55] *Ibid.*

Technical Advisory Committee (TAC). The committee submitted specific recommendations for the establishment of a specialist lab in ITRI that would act as the focal launching point for the industry.[56] In September 1974 the Electronic Industrial Research Center (soon renamed the Electronics Research Service Organization, ERSO) was established in ITRI, with its main goal being the development of technological capabilities to spur the growth of the semiconductor industry.

ERSO started to look for sources of IC fabrication technologies. However, it did not manage to find any suitable partners until, through Pan's influence, in 1976 RCA agreed to transfer its obsolete technology to ITRI. RCA had decided to get out of the semiconductor industry and saw this as an opportunity to earn royalties from its abandoned seven-micron complementary metal oxide semiconductor (CMOS) fabrication technology. This technology was already far behind the world limit of two microns. A group of forty engineers, many of whom later became the leaders of the semiconductor industry in Taiwan, spent almost a year in RCA's facilities in the United States, and ERSO built its first IC fabrication plant with RCA's guidance. In 1977–1978 the first trial wafers were produced, and the Taiwanese team started to test its own experimental designs. In 1979 the ERSO team advanced to such a degree that it had better yields than RCA's and started to sell small quantities of chips to supplement its financial resources.[57]

Thus by the late 1970s ITRI laid the technological foundation of Taiwan's semiconductor industry. The mere existence of ITRI did not, however, immediately solve the problem of coordinating the state efforts in technology development with industrial promotion of the developing technologies. The system was inconsistent with major organizational gaps in a cohesive institutionalized functions in industrial technology diffusion and commercialization.[58] This would change in the 1980s.

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[56] *Breznitz, p.105*
[57] *Ibid., pp.105-106*
[58] *Greene, p.118*

3 ITRI's institutional learning at the initial stage of Taiwan's high-tech industrial takeoff (the late 1970s-the late 1980s)

3.1 Systematization of the state's efforts in high-tech industrial development

The period from the late 1970s to the late 1980s can be categorized as a primarily systematization of Taiwan's high-tech industrial development in term of its functional fulfilment. In response to the increasing challenging domestic and international environment (the visit of President Nixon to China, Taiwan's lost of seat in the United Nations, and the first oil crises) of the early 1970s, the government quickly moved to establish a more self-reliant development strategy based on industrial consolidation and renewed export growth. The focus was shifted on the development of capital-intensive, heavy, petrochemical industries, as well as the major infrastructural upgrading (e.g., Ten Major Development Projects, started in 1973). The objective was to increase domestic production of intermediates needed for the rapid expansion of export industries. This was in effect a secondary phase of import substitution: although dependence on exports remained, many imported intermediates and capital goods were gradually replaced by domestically produced goods such as iron and steel, machine tools, and electrical machinery.[59]

Over the 1970s, the public sector was the prime beneficiary of the policies, in large because the bulk of restructuring projects could not be undertaken by the private sector. The secondary import substitution required large investments in technology- and capital-intensive industries with scale economies, investments the predominantly small-scale private sector did not have the resources to undertake. For this reason, the government used public enterprises much more actively than in the 1960s to provide momentum in industrial upgrading. To some extent, this rationale was reinforced by

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[59] *Dahlman and Sananikone, p.103*

the government's ideological distrust of big private business and its arms-length relations with the Taiwanese manufacturing sector.[60]

The trend was changed in 1978, when Chiang Ching-Kuo became the president of Taiwan, while the United States severed its relations with the country, the fact that sent shocks across Taiwan and quickened the pace of both economic and political liberalization.[61] Investment policies were revised so as to offer more inducements to investors in the targeted industries through tax relief, credits, and encouragement of business mergers. The second round of oil crises in 1979 spurred a shift in the emphasis of industrial policies toward non-energy-intensive, nonpolluting, and high-tech activities like machine tools, semiconductors, computers, telecommunications, robotics, and biotechnology.[62] However, this time the policy-makers determined a general push for advanced technology activities through a means of the private sector. This necessitated to close remaining gaps in institutional planning and implementation.[63] The issue was to foster the emergence of a whole new sector in the absence of significant infrastructures and competences inductive for high-tech industrial activities.

Throughout the period of the late 1970s to the late 1980s, the state apparatus pursued several important strategies to promote technological progress of the economy, including developing R&D in both the public and private sectors, pursuing a "government policy of promoting internationalization which encourages enterprises to develop international networking", and reversing the brain drain by attracting large numbers of scholars and experts (mostly from the United States) to return to work in Taiwan.[64] These strategies were designed and implemented by a new set of institutions that were put into place over the period.

The First National Conference on Science and Technology that took place in 1978 heralded a starting point. Organized by Kwoh-Ting Li (Taiwan's "Godfather of

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[60] *Dahlman and Sananikone, p.104*
[61] *Lin, p.194*
[62] *Wade, pp.97-98*
[63] *Dahlman and Sananikone, p.106*
[64] *Greene, p.120*

Technology"), the Conference was attended by 400 officials, entrepreneurs, scientists and engineers to evaluate the past S&T performance and the future direction of it. The Conference recommended four strategic areas for technology development: energy, automation, materials, and information technologies. In the following years, National Conferences on Science and Technology would be held every four years and in fact become the highest level for technology policy formulation in Taiwan. Based on the conclusions from the Second National S&T Conference, four more strategic technological focuses were added: biotechnology, electro-optics, hepatitis-B control, and food technology. The main discussions, however, were concerned with S&T manpower, which led to the implementation of the Program for Strengthening the Education, and Recruitment of High Level S&T Personnel in 1983.[65]

A second milestone in the evolution of the state's approach to S&T activities inductive for high-tech industrial development was formalization of foreign technology consultation into the Science and Technology Advisory Group (STAG) in 1979, headed by Kwoh-Ting Li and composed almost entirely of foreign or foreign-born Chinese advisors. STAG was designed to engage into S&T technology development planning, to provide consulting and evaluation services for it, and to facilitate cooperation between government agencies and enterprises.[66]

Based on the recommendations from the First National Conference on S&T, STAG drafted the Science and Technology Development Program, aimed "to effect an across-the-board development of S&T in order to fully develop the national potential, accelerate national reconstruction, improve living standards, and reduce reliance on external help".[67] The Program was approved in 1970 by the Executive Yuan and essentially was a proactive plan, built on a sophisticated understanding of the role that the state could play in fostering scientific development, as yet no Taiwanese companies were prepared in to invest in high-risk industry. The MOEA would sponsor projects aimed at upgrading industry, especially in the areas of information technology, industrial automation, materials, and energy. The responsibilities of

[65] *Dahlman and Sananikone, p.18*
[66] *Wessner, p.139*
[67] *Greene, p.127*

existing government R&D institutes – first of all ITRI – were refined and clarified. Another important facet of the 1979 S&T Development Program was the emphasis it placed on promotion of international technical cooperation, technology transfer, and strengthening contact with overseas Chinese.[68]

Another important R&D-related initiative in the 1979 S&T Development Program was the establishment of a science-based industrial park in Hsinchu. The project's objectives were "to promote the development of advanced technology industries, to cultivate scientific and technological manpower… [and] to encourage intensive research and development of industrial technologies".[69] The park was envisioned as a sort of state-designed S&T melting pot similar to Silicon Valley that would utilize Taiwan's indigenous state-sponsored S&T resources in combination with returning scholars and entrepreneurs and the know-how imported by foreign companies. However, most important, the Hsinchu Science Industrial Park (HSIP) was part of the state's strategy for encouraging the development of non-state-sponsored R&D by offering industries a complex in which they could be near each other, share facilities, and take advantage of the proximity of the ROC's most important state-owned industrial research facility – ITRI.

Therefore, by the early 1980s the system aimed at Taiwan's high-tech industrial development was institutionalized both in terms of its components and functionalities.

3.2 ITRI's institutional learning strategy during the stage

Facing a new environment with a more prominent and leading role of the state in its attempt to speed up high-tech industrial formation in the country in the absence of the private initiative, ITRI underwent its first "learning-how-to-change" process, which in effect made the institution's interaction with the other components of the system two-folded, based on either proactive (industry initiating) or reactive (technological support) approaches. The choice was determined by absorptive technological capacity of the targeted industry.

[68] *Greene, p.128*
[69] *Ibid., p.136*

In relation to the industrial targeting of the government, ITRI's research units and laboratories were refined and clarified to include electronics, machinery, materials, mining and energy, and chemical engineering. They were unidisciplinary (reflecting the unidisciplinary technological nature of industries at the time) and had a loose control from the ITRI's top administration, operating autonomously with separate funding. In case of energy, machinery and materials, technological capabilities of the local manufacturers were essentially sufficient, therefore ITRI assumed a technological support role in working with them. Under this approach, the units' "learning-how-to-learn" practices were institutionalized through conducting R&D projects that could enhance technological competence of firms in a related industry (Table 3-2-1). Once a technology was successfully developed, it would be transferred to the industrial partner either through licensing or technology assistance models. Therefore, the more technologies were transferred, the higher ITRI's impacts would be perceived, which subsequently helped ITRI to secure government funding.[70]

Table 3-2-1. ITRI's research units and their corresponding industrial counterparts at the initial state of Taiwan's high-tech industrial development

Major units of ITRI	*Industry counterparts*
Mechanical Industry Research Laboratories (MIRL)	Machine tools, industrial automation, metal foundry, motorcycle industries
Energy and Mining Research Laboratories (EMRL)	Mining industry, natural gas, solar heating, other energy-related industries
Electronics Research and Service Organization (ERSO)	Electronics, computer and peripherals, semiconductor industries
Material Research Laboratories (MRL)	Special materials for semiconductor, electronics, mechanical, bicycle and tennis racket industries
Union Chemical Laboratories (UCL)	Chemical, pharmaceutical and textile industries

Source: Chen and Chen (2016)

[70] *Chen and Chen, p.52*

However, the major impact of ITRI at this stage came from its activities in industry creation in the field of semiconductors. The more proactive approach was basically derived from the fact that the local electronics company at the time had only basic operation capabilities, with little or no capacity in design and engineering, and more importantly with no intentions to enter the field. Thus the successful experience in running the IC demonstration plant in the second half of the 1970s suggested a new model of ITRI's interaction with the sector – spinning-offs. Here the learning practice of "learning-how-to-learn" could be described as a three-phase process. First, ITRI would acquire a technology from abroad through licensing. The choice of the technology would be determined through a process of consultation with the governmental planning agencies and STAG, and would generally reflect a missing technological link of the emerging industrial sector. At the second phase, ITRI's ERSO would carry out a R&D project in order to understand, absorb and adapt the technology, including a construction of a demonstration plant to test its commercial reliability. Finally, the facilities, intellectual properties and human resources of the project would be spin off into a private company. This way, the spin-off companies would be used as a means of the industry flagships to reduce the perceived risks and thus attract more private companies entering the semiconductors manufacturing, consequently contributing to the formation of the industrial cluster.

In this stage, ITRI was mostly funded by government projects, while contracts from industry grew slowly over time in number and volume. To enhance industry creation capabilities of ITRI, the Industrial Technology Investment Corporation was established in 1979 as a wholly owned subsidiary of ITRI to conduct venture style investing for the new wave of technology firms expected to arise from the application of new technologies.[71]

[71] *Hsu and Nystrom, p.206*

3.3 Case study: semiconductors industry

The experience of the IC demonstration plant that had been set up by ITRI's ERSO in 1977 was very successful: a year later after its start the accumulated production output for the chip was over a million sets.[72] Despite the obvious commercial prospects of the technology and the strenuous urging of MOEA, leading electronics firms in Taiwan at the time (such as Mitac, Sampo, and Tatung) elected not to enter the semiconductor field at this stage, viewing it as still to risky (similarly, Korean electronics firms were likewise resisting the urging of government; Samsung and Hyundai delayed making major commitment until 1982-1983).[73] Facing a potential failure in transfer and commercialization of the technology, ITRI felt the urge to commercialize its technology by creating a spin-off. Dr. Ding-hua Hu and Dr. Chin-tay Shih, Director and Vice-Director of ERSO, respectively, argued with MOEA, saying: "to start up an IC company was critical for Taiwan's own IC technological development. If ERSO had not advocated the formation of a new company, then either the resources devoted to the pilot plant would have been wasted, or the multinationals would have absorbed the manpower trained by ERSO, hurting local IC development".[74]

MOEA accepted the proposal and invited some of Taiwan's biggest companies as investors. At first, none of the companies invited agreed to join. MOEA then used its direct influence and organized a coalition of local companies that finally agreed to invest in the project, and between them, 51 percent of the shares of the new entity, United Microelectronics Corporation (UMC), were distributed. The total sum invested stood between USD 14 million and USD 20 million. Apart from receiving all of its technical staff and technology from ERSO, UMC was also granted technical assistance from, and the use of, ERSO's fabrication plant. UMC quickly engaged in another series of fund-raising and built its own first fully owned fabrication plant in the newly established Hsinchu Park in 1982.[75]

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[72] *Huang, p.33*
[73] *Mathews and Cho, p.167*
[74] *Tzeng, p.113*
[75] *Breznitz, p.107*

ITRI's preeminence over the development trajectory of the Taiwanese semiconductor industry did not end with the spin-off of UMC. On the contrary, the successful launch of UMC encouraged subsequent formal and less-formal spin-offs, as teams of engineers left to establish their own companies. Following the establishment of UMC, ERSO itself slightly changed its focus to base the Taiwanese semiconductor industry around capabilities that would allow it to competitively and quickly design and manufacture custom-tailored (application-specific integrated circuit, ASIC) chips, and not just around specific products. The strategy focused on developing both ASIC capabilities and the fabrication technologies needed to manufacture them. ERSO managed to move its own fabrication capabilities to 4.5 microns in 1981 (still far behind the world's technological edge at the time at 2 microns), and to acquire and develop complementary technologies that would enable Taiwan to excel in ASICs. In the early 1980s ERSO expanded its capabilities in design, testing, and several other stages of IC production, including masking.[76]

At this point, senior figures in the government intervened to "raise the bar" of technical expectations in Taiwan. Strong support was expressed, by the President and Premier Sun, for ITRI's achieving VLSI (very-large-scale integration) capability. While UMC had argued that it was the appropriate vehicle, the view prevailed that it was premature to entrust such an important mission to a still small private firm. The aim of the VLSI project was to build a working VLSI plant at ERSO using VLSI technology and provide a Common Design Centre for chip design firms to develop application products. This time, ERSO did not turn to a large established multinational like RCA for technology import, but instead signed joint development agreements with Silicon Valley start-up firms such as Mosel and Vitelic to develop VLSI chips.[77] The outcome of the VLSI project was a set of designs and state-of-the-art technology in a specially built laboratory housed within ERSO, with a view to spinning it off as a going concern.

In 1985 Dr. Morris Chang was recruited as the new President of ITRI. He had wide experience of the global semiconductor industry and within weeks of his appointment,

[76] *Breznitz, p.108*
[77] *Mathews and Cho, p.169*

was invited by the government to propose a new spin-off venture from ERSO that would take Taiwan into the VLSI era. Instead of proposing a conventional semiconductor company with its own product portfolio, Chang advocated for a pure-play “silicon foundry” operating VLSI process technology to manufacture chips for small Taiwanese firms and international clients. This was a radical and innovative proposal, which promised to create not only a company with commercial success, but one that could extend fabrication facilities to the island's IC design houses. The plan was accepted by government leaders on ITRI's recommendation. The source of capital for such a large project (USD 220 million) remained the stumbling block. With substantial government support, Chang led the establishment of the world’s first semiconductor foundry, Taiwan Semiconductor Manufacturing Corporation (TSMC), becoming its first CEO in 1987. Like UMC, TSMC was spun-off by ERSO, which in 1986 set up a six inch VLSI preparatory manufacturing plant and in 1987 transferred it to TSMC. [78]

The formation of TSMC as a pure-play foundry, as well as UMC’s subsequent conversion into a foundry, changed the entire business model of the global semiconductor industry in a manner that worked to Taiwan’s advantage. Before the advent of foundries the semiconductor industry was vertically integrated, with manufacturing capital costs constituting a huge barrier to entry. The emergence of foundries enabled “fabless” design firms with no factories of their own—or associated capital costs—to challenge industry leaders with innovative designs involving modest investment costs. Numerous Taiwanese IC design firms sprouted up, utilized TSMC and UMC foundry services, and reaped enormous profits. A large number of expatriate Taiwanese “engineers-turned- entrepreneurs returned from Silicon Valley to drive this process forward.

[78] *Wessner, p.322*

4 ITRI's institutional learning at the stage of Taiwan's high-tech industrial consolidation (the late 1980s-the late 1990s)

4.1 Industrial and political shift at the turning of the 1990s

Due to the state's incentives put into the effect during the course of the 1980s, a growing number of small, high-tech firms in Taiwan started producing increasingly sophisticated and higher-value-added products, while the share of the labor-intensive, low-tech industries had steadily declined. In 1992, the share of highly technology-intensive products in total exports was nearly 30 percent, up form 18.4 percent in 1986.[79] These high-tech firms found synergies with each other and with the domestic R&D institutions, forming an integrated network, as was shown most clearly in the information industry. As a result, Taiwan passed the United Kingdom as the world's fifth largest producer of semiconductors by 1993. The total output value of the information industry products in 1995 reached USD 20 billion, making Taiwan one of the top free exporting countries of information products (after the USA and Japan).[80]

Following the establishment of TSMC in 1987, enterprises entering the field of semiconductor production in turn included Da Wang Electrics (1986), HMC (Hualon Microelectronics Corp., 1987), AMPI (Advanced Microelectronic Products Inc., 1987.), Winbond Electronics Corporation (1987), Holtek Semiconductor Inc. (1988), MXIC (Macronix International Co. Ltd., 1989), Texas Instruments-Acer Inc. (1990), Mosel Vitelic Inc. (1991). The number of manufacturers climaxed at twenty one in 1999. After the establishment of Syntekt Semiconductors (1982), He Teh Integrated Circuits (1983), Chip Design Technology, and Proton (1985), the number of IC design companies rapidly increased to sixty five in 1994, with annual sales of NTD 12.4 billion. Meanwhile, the flourishing semiconductor industry also drove the growth

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[79] *Dahlman and Sananikone, p.108*
[80] *Lin, p.198*

of the packaging industry. By 1994 there were eighteen package enterprises with totaling annual sales revenues of NTD 19.5 billion.[81]

The shift towards private initiative in high-technology areas has been made possible by the increasing scale and scope of Taiwanese private firms, particularly those firms that arose in the new technology products areas. To present some hard data on this shift using sales revenue in 1987, four of the ten largest manufacturing firms were state-owned. By 1999, only five of the top fifty were state-owned and only one of these was in the top ten, Chinese Petroleum. In 1999, the highest ranked high-tech firm was Acer, the second-largest manufacturing firm. In 1987, Acer was ranked fifty-third and UMC, the largest IC firm at the time, was ranked 122nd. Indeed, eight of the top 50 firms in 1999 were operating in the Hsinchu Science-based Industrial Park and four of the top ten largest firms were Taiwanese high-technology firms.[82]

Politically, economic prosperity became no longer a sufficient means of social consensus building. During the 1980s, Taiwanese politics had been dominated by the struggle between a KMR old guard upholding old-style authoritarianism and a Taiwanese society demanding greater participation in the political process. In many respects, these political changes stem directly from Taiwan's economic success. Higher living standards, exposure to foreign ideas, and education have created rising expectations and increased public demand for a better quality of life, including greater political participation, better environmental and consumer protection, and greater government accountability. Increasingly there were calls for greater social spending in areas such as health insurance, pension schemes, and education. Since the mid-1980s, the government had responded to the shifting structure of Taiwanese society by allowing more participatory policies. Since the martial law was lifted in 1987, Taiwan had gained the basic elements of a democracy – legal opposition parties, the right to organize political demonstrations, freedom of the press, and a broader electoral

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[81] *Cheng, B-S., pp.14-15*
[82] *Fuller, p.13*

process. The first president election in 1996 marked the culmination of Taiwan's changing political process.[83]

The rapid rate of technological change and increasing protectionism in industrialized countries made it difficult for Taiwanese firms to gain access to the kind of cutting-edge technologies necessary for the kind of breakthrough industries that the government favors. Moreover, the industry was still dominated by SMEs , which were not in a position to subsidize the R&D that was necessary to make in a situation of rapid technological change.[84] According to a 1989 MOEA survey, only 5,251 (6.8 percent) of Taiwan's 76,881 manufacturers were engaged in R&D in 1989, and among the SMEs that percentage was only 5%. Even among those involved, half spent less than NTD 1 million per year. As only 720 submitted patent applications in 1989, the R&D activities generally dealt with process improvement and improvement or changing existing products and appearance.[85] The decisive governmental support continued, but took the private sector needs as a starting point (not technology as it was during the 1980s) in its efforts to strengthen the industries' ability in high-tech manufacturing

In 1990, the Executive Yuan put forward the Six-Year Mid-Term S&T National Development Plan starting from 1991, which identified ten emerging industries and eight key high technologies. The eight key technologies were a mixture of old technological targets supplemented with some new technological areas: industrial automation, appliances of advanced materials, energy conservation, opto-electronics, computer software, advanced sensors, resource exploitation. The Program in many ways repeated what had been stated in earlier plans (increased investments, more efficiency, and more private sector involvement in R&D), but also pointed at new issues such as strengthening of IP rights protection, basic research, enhanced science education and creation of an information society.[86]

[83] *Dahlman and Sananikone, pp.116-117*
[84] *Ibid., p.108*
[85] *Lauridsen, p.34*
[86] *Ibid., p.18*

In order to prevent the hollowing out the economy as a result of foreign investments in Southeast Asia and Mainland China, and in order to speed up the development of new high-tech industries, a mixture of tax incentives and financial measures was introduced to promote a general upgrading of Taiwan's industries during the 1990s. The new Statute for Industrial Upgrading (SUI) made preferential tax treatment more functional (i.e. less sector- and enterprise-specific) and the financial schemes became more functional, that is programs were designed to promote industrial automation, training of personnel, strengthening of product quality etc., irrespective of the industries and sector concerned. The state's promotion policies changed in the 1990s into more genuine joint public-private research efforts.[87]

4.2 ITRI's institutional learning during the stage

The rapid growth of the Taiwan's high-tech industrial companies and the process of the democratization, which made the country's political machine more accountable and participatory, led to a disbalance in the high-tech developmental model. By the end of the 1980s, ITRI had became a subject to ambiguous criticism. On the one hand, private companies claimed that ITRI developed technologies for many industries without careful selection resulting in creation of ineffective technologies that did not match their needs. On the other hand, industrial leaders criticized ITRI for engaging too much in short-term technological development projects that had a limited technology value to the manufacturing sector.[88] Therefore, transformation and adjustment of ITRI's interactions with the environment was needed.

In its "learning-how-to-change" attempts to answer the criticism, ITRI once again refined and expanded its organizational structure to include more disciplinary spectrum and reflect more sophisticated needs of its industrial partners. The laboratories were still decentralized, but gained a higher degree of division of labor as technologies became more heterogeneous. Later in the period some of them would split out to keel the parent laboratory at a manageable size. [89] For example, as ERSO's

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[87] *Lauriedsen, p.24*
[88] *Diederen, p.222*
[89] *Hsu, p.1321*

research topics became more diversified and sometimes overlapped between different division, ERSO had to split optics and computer and communications into Opto-Electronics and System Laboratories (OESL) and Computer and Communications Laboratories (CCL), respectively. To respond to general needs of the industries, ITRI founded the Industrial Pollution Control Center (to respond to the issues in environmental protection measures), the Center for Environment Safety and Health Technology Development (to respond to industrial safety), and the Center for Measurements Standards (to maintain the national measurements standards to assure industrial qualities and metrology).

The most significant changes, however, concerned the ITRI's interactive "learning-how-to-learn" practices. While the two-folded model remained intact, both proactive and reactive approaches to the development and diffusing of technologies were refocused and expanded to include more application methods. To enforce its industrial relatedness, ITRI started using revenues earned from the industry as the measurement of its impact. In this relation the ITRI adopted two most influential policies: the "1-to-1" and the "walk-out-of-lab". The former implied that ITRI should earn an equal amount of income from the private sector without sacrificing government sponsored budgets. The latter required ITRI's engineers to visit a certain number of industrial firms every three months. These policies forced the researchers to understand the requirements of industry, and forced the adjustments of research topics from advanced towards near-competing technologies which were easier to diffuse.[90] Many laboratories recruited more non-research personnel to provide contract services, in order to earn more income from the industrial sector. For advanced projects, ITRI started to take surveys as a part of the process of selecting technology for development projects. Besides, industry and academic experts were invited to participate in research planning process and offer criticism and appraisal in order to ensure that technology development would meet actual industrial needs.[91]

In relation to industry initiating activities (proactive approach), ITRI's "learning-how-to-learn" gradually transformed from the creating flagship companies to a consortium

[90] *Chen and Chen, p.55*
[91] *Hsu, p.1321*

initiator to overcome network and production failures among local firms from the same industry. ITRI started to act as an intermediary and a resource provider to diffuse and upgrade existing technologies and building trust between participating firms. They were around 30-80 small and large consortium set up by ITRI, depending on definition. Some consortia were tightly knitted, as members including ITRI jointly decided on technologies and strategies. Some were loose and informal, which ITRI only had roles in providing market and technology intelligence. While, some organically developed from informal and loose to formal and tightly knitted ones.[92]

4.3 Case study: PC industry

The creation of the IC industry over the 1980s was the most shining example of the ITRI's efforts in industrial technology development and diffusing, but the IC industry gradually gave rise to a cacophony of private industry voices increasingly critical of the ITRI's engagement with this sector. The ITRI's efforts came under attack relatively early in the industry's development. UMC criticized the VLSI project that created TSMC in 1986 because UMC viewed the project as taking away resources from UMC, the first state-sponsored company. Later, Acer attacked the next project, the submicron processing technology (undertaken by ITRI during 1990-1995), from the very beginning as waste of government resources to develop more advanced process technologies and memory technologies. Acer had already agreed to build an advanced memory fab with TI (Texas Instruments) in 1989. As the project drew to a close in 1993-94, UMC and TSMC quarreled over the spoils of the submicron Project, a new fab that eventually became Vanguard. ITRI's budget was cut in half in 1994 by the Legislative Yuan in wake of the criticism of the submicron project as a funnel of public funds to what were deemed to be mature private enterprises.[93]

While ITRI's funding subsequently recovered, the scope for public initiative in the area of ICs has narrowed considerably. In the late 1990s, ERSO tried to organize a consortium to research future generations of process technology, ASTRO. However, the technology leaders, TSMC and UMC, were not interested in joining. The other

[92] *Intarakumnerd and Goto, p.30*
[93] *Fuller, p.12*

major IC fabrication firms were interested in joining, but these firms were not as technologically sophisticated as TSMC and UMC. Indeed, the underlying motivation of the project was to help the lesser firms upgrade. In the end, no project was tenable in terms of obtaining the large amount of government resources necessary without the participation of the leading firms, TSMC and UMC.[94]

In this relation, the main mechanism for ITRI's proactive strategic engagement with Taiwan's high-tech industrial development became formations of consortia. As it was vividly argued by John Mathews, the main goal of the ITRI's R&D consortia comprised technological learning, upgrading, and catch-up as part of attempts at industry creation. By 1990 the Taiwanese industry was firmly established in desktop computers and other related products; nonetheless, its technological capabilities were still far behind what was needed to succeed in the lucrative new laptops market. ITRI's CCL (Computer and Communications Laboratory) formally drafted the project as an R&D consortium with the aim of developing a set of key components to become the standard on which the different companies would build and develop their products. The biggest computer-manufacturers trade association in Taiwan was involved and recruited as a joint coordinator.

In July 1990 the Taiwan Laptop Consortium, with forty-six subscribing companies, was officially announced with capital of USD 2 million[95]. The project was concluded quickly, and by the end of 1990 Taiwan achieved the status of the world's leading supplier of laptops. This time CCL not only transferred prototype machines but also constructed extensive training programs, and many of its staff moved to private firms. The main problems of the project were oversubscription and a too tight division of labor. The companies, given an almost complete product that had been developed solely by CCL, were unable to differentiate and further develop their products, leading to a relentless price competition among the Taiwanese companies. These lessons were learned, and throughout the ITRI-led consortia in the 1990s, private companies were given slightly greater R&D responsibilities, or at least slightly more-flexible prototypes. In some of the projects one of the declared aims was the creation

[94] *Fuller, p.12-13*
[95] *Breznitz, p.115*

of R&D, or at least integrated design capabilities, within the participating private companies.[96]

[96] *Breznitz, p.116*

5 ITRI's institutional learning at the stage of Taiwan's high-tech industrial maturation (the late 1990s-present)

5.1 Economic and political shift at the turning of the 2000s

The turn of the century saw a change of guard when the DPP candidate Chen Shui-Bian won in the presidential election of 2000. As a "divided government" emerged after the election, with the president and the parliamentary majority (still held by KMT) belonging to different political parties, the state began experiencing a period of policy paralysis and internal confusion. Many governmental proposals and measures found great difficulties in getting through the legislative process. It was common for government agencies to see their entire budgets frozen by the parliament for not meeting the demands of the legislators. Therefore, the strategic planning and implementation by the state's bureaucrats were undermined, whereas the government's policy became more and more a reflection of ideological cleavage between the two political camps.[97]

A major shock rocked the business community in October 2000, when the newly installed administration decided to reverse the long-made plan of building the fourth nuclear plant, which had been already under construction. In response to the news, the stock market plunged down: the total market value of the stocks shrank by more than 40 percent. Further hit by an international slowdown in the wake of 911 incident, Taiwan's economy experienced its first annual decline in the post-War era, when the growth dropped from nearly 8 percent in early 2000 to minus 2.17 in 2001. Both exports and imports shrank precipitously by over 20 percent.[98] Manufacturing output declined 5.73 percent against the background of falling private investments with annual growth rates being minus 20.6 percent, minus 2.15 percent and minus 2.03

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[97] *Wu, p.984*
[98] *Ibid., pp.991-992*

percent for the years of 2001, 2002, and 2003, respectively. [99] The business sector lost its confidence in the governments' ability to to lead the economy.

With the weakened and divided state, private companies assumed a new leading role in the course of Taiwan's high-tech industrial development. Indeed, after two decades of intensive growth and rising technological capabilities, Taiwan's high-tech became globally competitive. The share of exports in high-tech industries accounted for 42.3 percent in 2006, second only to Singapore and Ireland. In terms of production value, Taiwan was the second largest country in the computer industry, and the fourth largest in the semiconductor industry. In 2008, Taiwan was ranked number two worldwide in IT industrial competiveness by the Economist Intelligence Unit (EIU).[100] Therefore, many manufacturing enterprises became powerful enough to the extent to challenge the state's vision and policies. Prior to the 1990s, Taiwan had only a few large private enterprises that did not rely on the local market for their development and survival, and therefore could exercise a considerable level of independence from the government's actions.[101] During the 2000s, however, with the rise of high-tech manufacturing, particularly in IT-related fields, the country saw the emergence of such an array of privately-owned firms. For example, Table 5-1-1 shows Taiwan's top twenty private companies in 2008 by R&D investments, which in total accumulated one third of the national R&D spending (USD 11 billion).

As it can be seen on Table 5-1-1, high-tech industries with the highest R&D intensity ratios are IC manufacturing and design. This is explained by the fact that Taiwan's IC sector, particularly the two foundry firms – UMC and TSMC – closely approached the technological frontiers, entailing a substantial increase in R&D investment. On the other hand, most of the Taiwanese firms in the computer- and display-related sectors are OEM or ODM manufacturers. Their scales of production have been quite large in the area of LCDs, notebook computers, mobile phones, CDs, and digital cameras.

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[99] *Chu, p.145*
[100] *Wang and Ma, p.286*
[101] *Chu, pp.141-142*

Table 5-1-1. Taiwan's top twenty high-tech private companies by R&D expenditure, 2008

Company	*R&D expenditure (USD million)*	*R&D intensity (R&D/Sales, %)*	*Ranking (2008)*	*Ranking (2007)*
TSMC *(IC manufacturing)*	*629*	*6.16*	*1*	*1*
Mediatek *(IC design)*	*480*	*22.24*	*2*	*3*
HTC *(OBM)*	*305*	*6.30*	*3*	*13*
Hon Hai Precision *(OEM/ODM)*	*291*	*0.62*	*4*	*7*
UMC *(IC manufacturing)*	*260*	*8.86*	*5*	*2*
Nanya Technology *(IC manufacturing)*	*203*	*17.62*	*6*	*6*
Chi Mei *(LCD)*	*202*	*2.06*	*7*	*4*
Wistron *(OEM/ODM)*	*197*	*1.47*	*8*	*10*
Asustek *(OBM)*	*174*	*2.20*	*9*	*5*
Quanta *(OED/ODM)*	*171*	*0.71*	*10*	*11*
AUO *(LCD)*	*169*	*1.26*	*11*	*9*
Compal *(OED/ODM)*	*150*	*1.18*	*12*	*14*
CPT *(LCD)*	*135*	*4.26*	*13*	*8*
Inventec *(OEM/ODM)*	*117*	*1.05*	*14*	*20*
Powerchip *(IC manufacturing)*	*109*	*6.53*	*15*	*17*
CHT *(Communications)*	*100*	*1.69*	*16*	*16*
Realtek *(IC design)*	*99*	*18.78*	*17*	*21*
Novatek *(IC design)*	*90*	*10.90*	*18*	*29*
Macronix *(IC manufacturing)*	*86*	*11.69*	*19*	*19*
ProMOS *(IC manufacturing)*	*80*	*8.23*	*20*	*18*

Source: ICT, 2011

However, their survival and development have mainly depended on how their customer companies (the brand name owners that provide critical technology know-how) fared in the world market, rather than on in-house R&D or government initiatives, instead of government assistance, although they would still benefit from the general fiscal, infrastructure, and financial environments of the economy as a whole.

The cost pressure on the OEM/ODM firms has been unceasing even as the absolute size of these firms and their shares of the world market have increased through consolidation. One method the Taiwanese have pursued is to cut cost by moving production to low-wage parts of East Asia, principally China. During the 1990s, there has been a progressive movement of Taiwanese IT hardware production out of Taiwan. The first items to leave were low-end peripherals, such as keyboards and mice. Then, scanners, monitors and motherboards followed in the latter half of the 1990s. In the late 1990s, desktop production began to move abroad and now notebook computer manufacturing is beginning to leave Taiwan. Production abroad topped fifty percent in 2000.[102]

The movement of production overseas has only allowed the Taiwanese firms to continue to compete in a product market with razor thin margins. It has not enhanced the margins, enabling the Taiwanese firms to move away from products in which they are dependent on their branded customers. The Taiwanese PC firms have tried to resolve these problems of low margins and dependency by diversifying away from their dependency on the PC market. These firms are gradually moving toward a wider platform of products similar to the platform of the contract electronics manufacture, which is now about twenty percent of their total product portfolio.[103] The logical move has been to develop smart hand-held devices as these products, such as personal digital assistants, within the IT sector. Cell phones are another area the PC manufacturers have been trying to enter (for example, Asustek and Acer). Again, the Taiwanese manufacturers have pursued these developments in conjunction with

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[102] *Fuller, p.17*
[103] *Ibid.*

foreign firms, showing a greater measure of independence from the Taiwan's governmental efforts and mechanisms of technology upgrading.

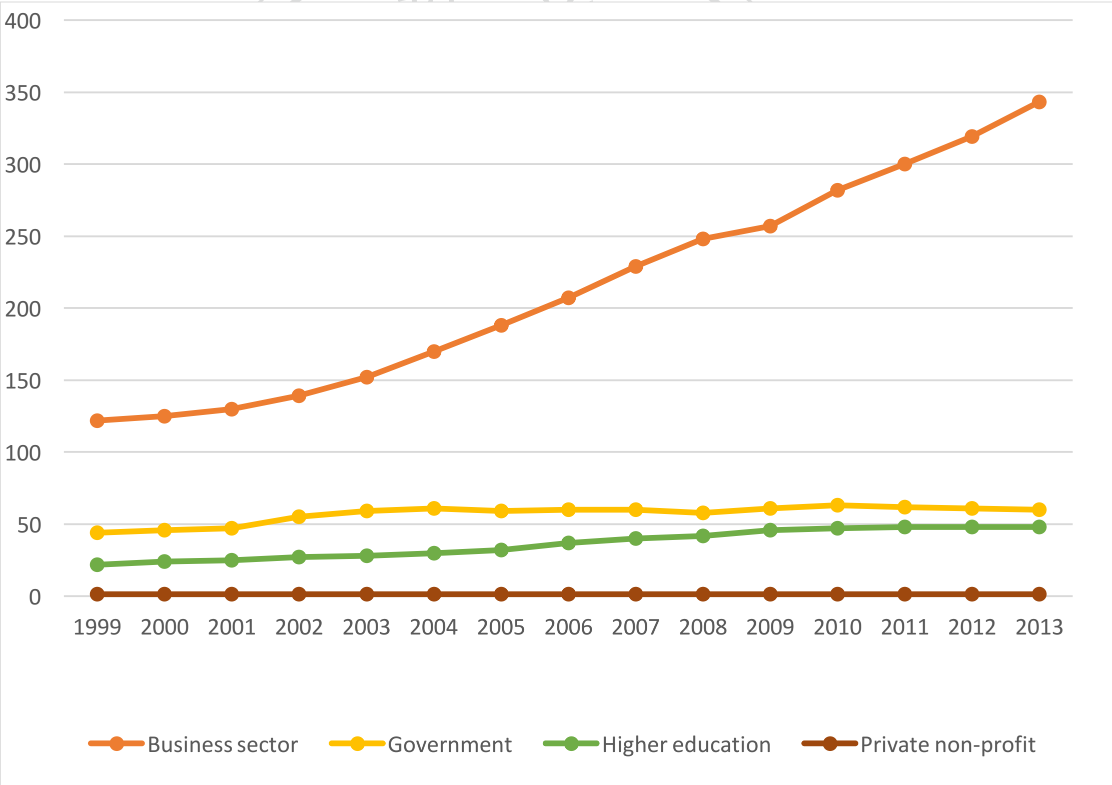
Despite the rise of the private companies in their technological capacity, the weakened state in Taiwan nevertheless continued to pursue growth in strategic industries through deepening (IT sectors) and enhancing of innovation culture (biotechnology). In 2001, the Executive Yuan passed the 2001-2004 National S&T Development Plan aimed for Taiwan to achieve the level of the developed countries in technological development within ten years. The Plan laid out the following goals: strengthening the knowledge innovation system, boosting industry's competitive advantages, improving citizens' quality of life, promoting sustainable development, improving nationwide technological standards, and reinforcing the country's autonomous defense capability.[104] On the regional level, Taiwan's municipalities started to play a more prominent role in encouraging local high-tech development. The most striking example is the city administration of Taipei that became much more interventionist in promoting high-tech concentrations of firms, such as software firms in the Nangang software park and medical and health-related firms in the Beitou-Shilin technology park.[105]

In relation to the legal framework governing the research activities of universities and PRIs, significant changes were enacted in 1999, when the government enacted the Basic Law on Science and Technology, modeled on the US Bayh-Dole Act of 1980. The Law reorganized the management of IPRs in public institutions and freed them (particularly universities) to more effectively generate and protect intellectual property while contributing more directly to the nurturing of new high-tech firms. To promote the programs related to intellectual property and technology transfer, the NSC called on universities and PRIs to examine their frameworks for dealing with IPRs and technology transfer. Later in order to integrate academic resources and effectively manage R&D results, the Department of Industrial Technology (DOIT) of MOEA launched a new set of policies relating to "Encouragement of Industrial Innovation and R&D". This was adopted in 2001 after discussion at the Economic

[104] *NSC, p.1*
[105] *Mathews and Hu, p.1006*

Development Conference. Three mechanisms for technology dissemination between industry and universities were put into practice: Technology Transfer Centers (TTCs) and universities; Technology Trade Centers (usually web-based systems); and incubators. These are all models of public-private interaction that have been developed in the advanced countries, now being emulated by Taiwan.[106] Consequently, R&D activities of the academia in relation to Taiwan's high-tech development have obtained more considerable position and showed a steady growth during the period (Figure 5-1-1).

Figure 5-1-1. Taiwan's R&D expenditure by sector of performance, 1999-2013 (NTD billion)



Source: DGBAS (2014)

5.2 ITRI's learning strategy during the stage

In the situation of the rising R&D capacity of the high-tech sector and the greater involvement of the domestic universities into technology commercialization

[106] *Mathews and Hu, p.1010*

processes, whereas the state's ability to "govern the market" has been declining, ITRI's model of interaction with the other players has changed considerably as the institute has been seeking a new role in the emerging knowledge-based economy of Taiwan. From the technological point of view, ITRI has been trying to move away from a catch-up paradigm of the previous period and to focus on innovation in an environment where local firms are still rather conservative in accepting technology risks.[107]

In its "learning-how-to-change" attempts, ITRI adopted three major strategic approaches: strengthening the functions of the headquarters, improving the multidiscipline infrastructure and human resources, and seeking new organization structures capable of generating advanced technologies, while remaining flexible in handling emerging applications.[108] Under the first approach, the institute's headquarters became "the brain" to think and plan for future directions of ITRI's interactions with the environment. First, the headquarters started an institute-wide process aimed at improving of R&D administration. Based on the principle of the "e-3P" (Project Management, Promotion Management, and Protection of IP), the non-unified management systems of the research units were consolidated into twelve standardized core processes run by a centralized Enterprise Resource Planning (ERP) system. This greatly reduced the transaction costs of cross-unit cooperation and personnel exchange, thus laying down a critical foundation for the following organizational restructuring.

The multidiscipline focus was introduced through a means of focus centers, i.e. flexible units tasked with integrating technologies developed by the core laboratories

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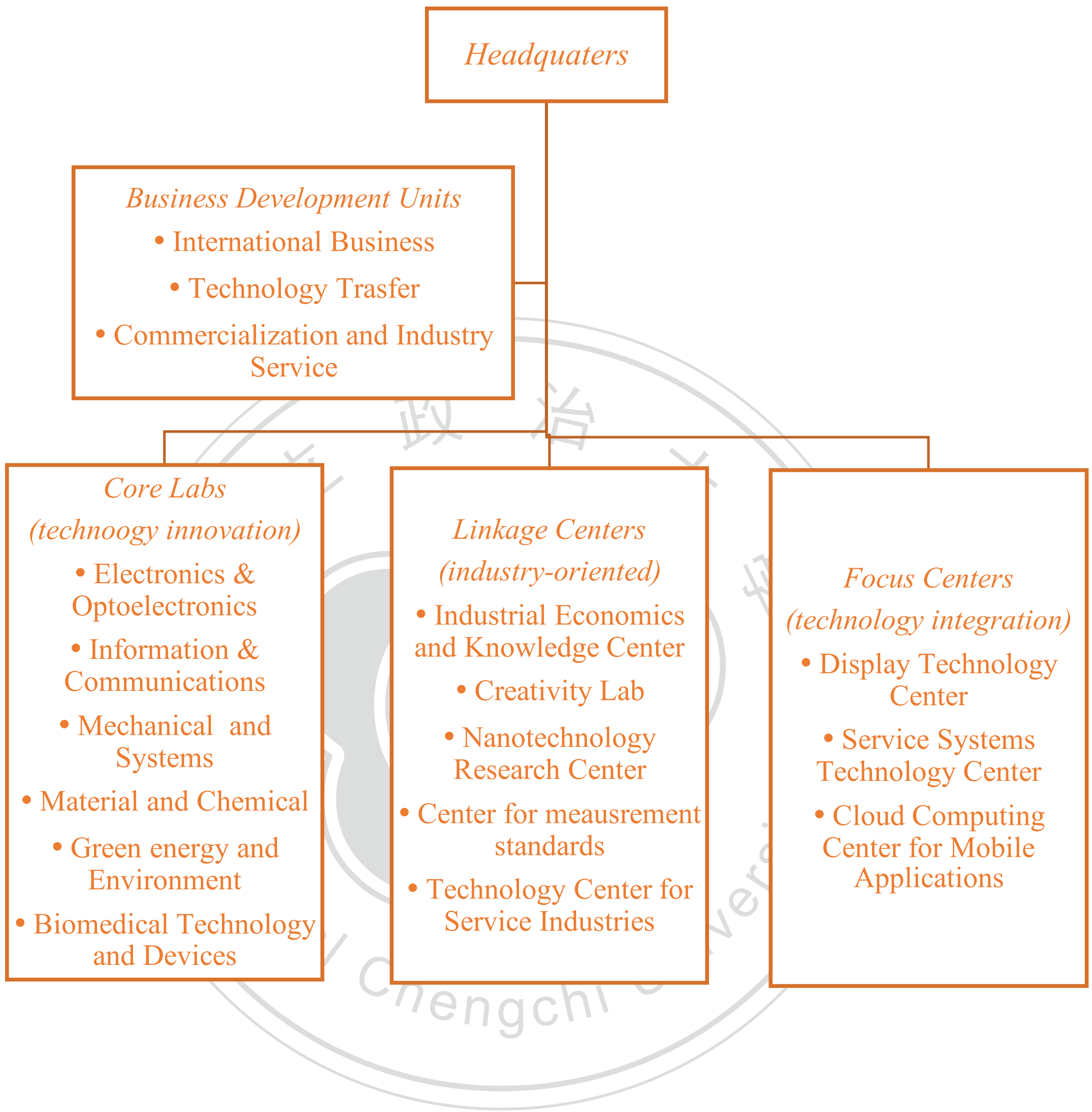
[107] *Mina, p.17*
[108] *Chen and Chen, p.57*

Figure 5-2-1. ITRI's organizational structure in 2012



Source: IEK (2012)

to explore their cross-disciplinary application with the infrastructure support of the linkage centers (Figure 5-2-1). The core laboratories under the new organizational arrangements were reoriented into six major fields: IT and optoelectronics, information and communications, precision machinery, materials and chemical engineering, biotechnology, and sustainable development. These six broad fields were each subdivided into the following research types: advanced and innovative technology, key component technology (exploratory projects), and R&D

infrastructure technology.[109] The main mission of the institute, however, was left without changes – to support key technologies in existing industries and to focus on developing potential industries within five-ten years. Nonetheless, the difference from the past is on the strategy to achieve the goal of supporting industry. In the past, ITRI's main strategies were to localize and diffuse foreign technologies. At present, ITRI has obtained enough capabilities to develop its own technologies in collaboration with strategic partners like big firms and universities.[110] In addition, ITRI has established joint research centers of small proportions at six national universities in nano-materials and biomedical, micro-to-nano manufacturing engineering, semiconductors, environmental technologies, communications and IC chips, optoelectronics. Agreements entail the sharing of staff (all of whom already have positions at either ITRI or the university), facilities and IP. International co-operation with global leaders in research has also become highly important: a mechanisms of institute-to-institute relationships, for example, has been put in place to develop cutting-edge research in areas of strategic importance.[111]

ITRI's research projects fall into two categories: technology development projects (contracted with MOEA and NSC) and industrial service projects (contracted mainly with the private sector, but also occasionally with MOEA). Financial resources for the technology projects are allocated in the following manner: a quarter of the research budget goes to advanced innovative projects, exploratory projects receive another quarter, while R&D fundamental construction projects enjoy a half of the research budget. The project proposal is both top-down (ITRI's R&D Planning Division) and bottom-up (research units) process. Project selection takes place through an evaluation process in the Advanced R&D Advisory Committee, which includes the top level management of the research unit, consultants, (including professors from universities), and international experts.[112]

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[109] *Hsu, p.1321*
[110] *Intarakumnerd and Goto, p.34*
[111] *Mina, p.17*
[112] *Mina, p.16*

Commercialization activities of ITRI are carried out at two levels. Most activities (technical services for near-competition technologies) are at the level of the research units, which have around 30 to 40 non-research staff responsible for technology transfer to the industrial partners. At the second level the Commercialization and Industry Service Center concentrates only on multi-disciplinary and strategic projects that involve advanced technologies. The center adopted four models of interactions with the private sector[113]:

1. Technological solutions for large industrial companies (e.g., TSMC, Falcon, Hitron Technology), which prefer to work with ITRI on one-to-one basis, are offered through a single contact window – the so called “key account management system” ;
2. Services to SMEs are provided under financial support from government programs, especially the Small Business Innovation Research (SBIR). Besides, the Center provides consultation to SMEs on how to apply for government R&D supporting programs;
3. Strategic venture activities are carried out through spin-offs and spin-ins. The former implies that a research team that developed technology with strong economic prospects and intellectual property rights can set up a new company. In this case, ITRI’s own venture subsidiary takes a minority share in the new company to create confidence among private investors. Alternatively, ITRI’s team can set up a new business unit inside a large existing company;
4. The Center also offers incubation services. Prospective “incubates” must be less than 18 and possess technologies or products that are innovative or advanced for Taiwan with a significant industrial impact. The period of incubation within ITRI is three years. Tenants have access to all of the ITRI’s technical and business supporting services and tailor-designed training programs. By the end of 2006, 145 start-ups had been formed with a total issued capital of USD 1.7 billion. Of these, 36 were located in science parks and 14 had made initial public offerings.[114]

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[113] *Intarakumnerd and Goto, p.32*
[114] *Sheu, p.20*

Table 5-2-1 demonstrates major parameters of the ITRI's interaction with the other components of Taiwan's NIS. The ratio of R&D funding generated from the public sector to that of the private sector has been around 1:1, demonstrating industrial connections of ITRI's R&D activities. With more than 70 per cent of the total employees in ITRI having higher education, the high annual turnover rate has been around 8-18 percent, slowing down at times of economic slowdown (e.g., during 2008-2009). In particular, the significant increase of formation of R&D partnerships and spin-offs demonstrates that ITRI's accumulated innovation capability has reached a significant milestone, whereby its R&D activities have been moving from pure applied research in to a judicious mix of basic and applied research activities.

In terms of patents, ITRI in 2000 established an IP platform in the form of the Technology Transfer and Service Centre to develop technology transfer and service regulations, upgrade the IP information system to promote innovative research environments, and implement effective licensing mechanisms. The production of "quality patents" has become a main goal of ITRI's patenting strategy to enforce the option of retaining fundamental IP to favour the creation of start-ups.[115] The number of patents awarded to the ITRI in 2003, 2004 and 2005 was 520, 712 and 663 respectively. The ITRI has a policy of acquiring foreign patents if they are necessary to complete a patent portfolio that will lead to the commercialization of new products (as was in case of flat panel displays). In 2005, seven per cent of the ITRI's total revenue was generated from its intellectual property rights.[116]

[115] *Wong et al., pp. 167, 169*
[116] *Intarakumnerd, p. 22*

Table 5-2-1. ITRI's inputs and outputs, 2000-2013

	2000	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
R&D funding from government, USD M	390	252	247	262	288	237	270	258	280	288	304	311	291	303
R&D funding from private sector, USD M	337	182	195	217	258	277	262	274	286	248	306	345	330	310
Total employees	5,965	6,068	6,302	6,193	6,069	5,442	5,815	5,785	5,912	5,824	5,823	5,808	5,756	5,678
With Master's and Doctorate's degrees, %	70.2	71	72.7	72.1	72.4	73.2	73	73.5	74	75.5	75.8	77.2	78	77.9
R&D staff, %	77	80.1	81.2	81.8	81.1	82.8	83.4	84	84.4	84.2	83	82.4	n/a	n/a
Turnover rate, %	18.6	10.3	10.4	8.4	12	21	12.8	12.8	11.1	5.6	9.3	10.6	n/a	n/a
Training courses held	n/a	n/a	n/a	631	495	n/a	n/a	n/a	n/a	580	n/a	n/a	n/a	n/a
Trained manpower	n/a	n/a	n/a	31,446	17,567	n/a	n/a	n/a	17,062	14,140	n/a	n/a	n/a	n/a
Technology transfer, cases	471	337	414	520	712	663	694	503	512	548	562	598	590	n/a
Technology transfer, companies	686	471	542	641	825	851	766	620	626	630	695	639	646	n/a
Technology transfer, value, USD M	n/a	n/a	n/a	23.8	35.4	38.3	41.5	45.8	48.2	35.6	63.3	64.3	42.0	31.3
Technology services to industry, cases	42,646	30,427	25,812	25,846	27,282	26,358	22,970	n/a	15,460	15,309	15,319	15,197	14,228	n/a
Services provided to SMEs, %	n/a	n/a	n/a	n/a	n/a	65	n/a	73	73	74	74	74	73	n/a
Research alliances, cases	n/a	n/a	n/a	n/a	6	n/a	n/a	n/a	n/a	53	34	37	23	n/a
Spin-offs	0	1	2	1	6	6	3	2	1	1	3	5	6	9

Source: Wong et al. (2015)

5.3 Case study: biotechnology industry

Taiwan has been promoting the development of a biotechnology industry since the early 1980s, but not much happened until in 1995, when the Advisory Committee for Promoting Biotechnology Industry was for formed and an action plan was adopted. Later it was given unprecedented prominence in the early 2000s by the DPP government, which saw in biotechnology a new flagship industry that would fuel Taiwan's future economic growth. The results to date have been mixed at best, despite a massive deployment of government resources.[117] Unlike strategic industries that the state previously designated, biotechnology is an innovation-driven, knowledge-intensive industry that relies heavily on original research. Furthermore, the structure and characteristics of pharmaceutical production requires long periods of time and an extremely large investment of R&D before a new drug is safely marketable. It is estimated that, on average, a new drug costs more than USD 200 million and takes 12 years to develop.[118]

Despite all the obvious problems, the DPP government nevertheless pushed for the expansion of the biotech industry. In contrast to Taiwan's developmental effort in microelectronics, in which ITRI was the governmental entity responsible for promoting the industry, in biotechnology, Taiwan's "the agencies and units involved are so numerous and diverse that a serious coordination problem has emerged."[119] Instead of a single main technology cluster (Hsinchu) which characterized the formative years of the semiconductor industry and continues to account for most of the semiconductor industry's output, Taiwan has already established six biotechnology parks with more planned. The Development Center for Biotechnology (DCB), a government research organization formed to play an ITRI-like role as a technology intermediary – turning basic research into commercial products – has drifted into an emphasis on basic research.[120]

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[117] *Wu, pp.996-998*
[118] *Liu, p.343*
[119] *Wu, p.997*
[120] *Wessner, p.332*

ITRI has long taken the position that Taiwan's developmental efforts in biotechnology should be limited areas where the country could leverage existing strong competencies rather than risky areas with uncertain prospects. ITRI has argued that Taiwan should seek to integrate its medical research infrastructure with its strengths in electronics and the information and communications technologies. ITRI also favors establishment of a few centers of excellence in the handful of medical areas in which Taiwan is a world leader – most notably liver diseases – in order to attract multinational biopharmaceutical companies to the island for R&D.[121]

In 1999, ITRI established a Biomedical Engineering Center (BMEC), which was split in 2006 to form the Biomedical Engineering Research Laboratories (BEL) and the Medical Electronics and Device Technology Center (MED). In July 2000, ITRI announced the establishment of Taiwan Biochip Association, which allowed the integration of Taiwan's limited resources, provided training to a new generation of biochip professionals, and also built mutual aid and communication channels. BMEC's Biochip Program combined research efforts of five ITRI laboratories to develop DNA microarray and microfluidics technology, which is essential to the rapid unraveling of the human genome. Sixteen patents from this effort were transferred from ITRI to a spin-off company, Phalanx Biotechnology Group, established in 2003. The research effort organized by ITRI drew in the Canadian Genetic Diseases Network (CGDN) and the Information System for Biotechnology (ISB), a US-based research organization. Using ITRI's technology, Phalanx was able to drop the price of one gene chip from about USD 1,000 down to USD 50-80 per slide.[122]

In 2002 ITRI spun off CESCO Bioengineering Co. Ltd. comprised of eight team members from ITRI's Tissue Engineering and Biomaterial Laboratory, to commercialize high cell density culture technology. CESCO developed a novel disposable pact bed contractile (DPBC) bioreactor suitable for producing various proteins and viruses and non-adherent cell cultures including embryonic stem cells.[123] In 2003 ITRI co-established the Biomedical Research Center with National Taiwan

[121] *Wessner, p. 333*
[122] *Ibid., p.332*
[123] *Ibid.*

University (NTU). The Center is endowed to organize annual forums, seminars and conference proceedings for the purpose of knowledge sharing and strengthening interaction in the following research areas: molecular diagnosis and treatment of deceases, cell therapy, animal models, diagnosis of cancer markers.[124]

ITRI spun off DailyCare Biomedical in 2004 to commercialize low cost, portable medical devices for home core users. The company's new CEO was K.P. Lin, the former chief of ITRI's Biomedical Engineering Center. The care technology underlying one of these products, ReadMyHeart, a portable electrocardiogram, was developed by ITRI's BEL. This product was approved for use in Japan in 2007, representing the first non-Japanese company to obtain a class-II medical device license under Japan's Pharmaceutical Affairs Law, which took effect in 2005.[125] In 2012 ITRI's developed developed a new foamy collagen substitute to reduce the risk of brain tissue damage in cerebral operations. The technology was transferred to Taiwan Biomaterial Company, another spin-off from ITRI.[126]

[124] *Wong et al., p.172*
[125] *Wessner, pp.331-333*
[126] *ITRI (2012), p.33*

6 Challenges and prospects of the ITRI model at the current stage of Taiwan's high-tech industrial development

6.1 Enterprise scales and the trade-offs between long-term and short-term objectives

The ITRI model of the government-led high-tech industrialization has demonstrated successful achievements in terms of increasing economic output and technological sophistication of Taiwan's industries. However, now it also reveals vulnerabilities that can substantially erode the gains which the country has made since the 1970s. Despite the fact that new opportunities emerged as the local technology companies have grown larger and, therefore, more capable of undertaking large-scale research efforts, in high-tech manufacturing the typical firm is still a small and medium enterprise in OEM production. In fact, SMEs (with less than 200 employees) account for over 93 percent of the manufacturers in electronic parts and components, 95 percent in computers, electronic and optical products, and 99 percent in machinery and equipment.[127]

It was these companies that proved particularly vulnerable to the global economic downturn, which began in 2008.[128] While many small and medium enterprises are flexible in their strategic adjustments and rapid responses to customers, they frequently lack the resources and skills needed to bring new products to the global market and to build brand recognition. Therefore, the survival of SME has been traditionally depended on predominantly entrepreneurial activities such as the following:

- Interpersonal and business networks are firmly established. Small businesses form tight networks encompassing personal and business relationships. Such

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[127] *DGBAS (2011)*
[128] *Wessner, p.310*

networking not only relates to commercial activities but also to sources of information and financial aids; [129]

- The business linkage scenario that places a large firm at the center and small firms as the surrounding stars is termed a center-satellite system. Such systems are initiated and sustained by the division of labor as well as by competitive niches that generate net benefits over the transaction costs induced by cooperation (including technology diffusion) and sub-contracting among legally independent firms in Taiwan. These layered networks were inserted into the global production chains that dominated the world of computer producing firms. At the head of these chains were the main computer companies such as Dell, IBM, Hewlett Packard, Apple, NEC, Toshiba, and Fujitsu;[130]
- Manufacturing-oriented process that does not require intensive R&D. Official statistics indicates that more than 90% of SMEs conduct hardly any technical research. Instead they concentrate their attention on cost-down activities to produce lower value-added products. Therefore their technical advancements heavily depend on purchasing of new production equipment, hiring the qualified technicians, and skills learned from daily practice.[131]

One of the most important considerations underlying the creation of ITRI was the recognition by the government that Taiwan's small companies could not afford the equipment, training and other costs associated with advanced R&D. While ITRI has partially offset this intrinsic disadvantage, turning its research into a system with strong division of labor, SMEs that have achieved technological breakthroughs remain vulnerable to competitive challenges from large multinationals. For example, when Microtec established the first computer-affiliated scanner in the world, roughly twenty similar local companies entered the filed, and for a time Taiwan was the world's leading producer of scanners. However, when major image-processing firms

[129] *Liu, pp.344-345*
[130] *Fransman, pp.211-212*
[131] *Liu, p.345*

entered the field (e.g., Cannon, HP), Taiwanese scanner firms were driven from the market.[132]

The government of Taiwan commonly seeks to offset the fact that most companies are too small to undertake expensive research by forming them into technology alliances. ITRI bases the alliances on its laboratories, which it uses to teach small firms to catch up with leading edge technologies sufficiently to enable them to perform contract work for the industrial chains of larger Taiwanese and foreign high tech enterprises. As a result, larger Taiwanese firms like Tatung, Acer and Mitac can rely a vast pool of loosely affiliated suppliers of a small scale, to which they pass on variety of low-margin, yet quite demanding manufacturing and design tasks (the center-satellite system). ITRI commonly encourages SMEs in such alliances to divide up research tasks, to specialize and to avoid duplication of effort. Organizing successful technology alliances is challenging and a number of them have failed due to divisions among the participating companies.[133]

Similarly, ITRI's interaction with large high-tech companies over the years has also become a source of controversy. One of the major point became the establishment of spin-offs, which was viewed by many private firms as a practice of unfair competition as the spin-off companies participated in market operations with the normal enterprises, while enjoying the advantages of the government's subsidy and advanced technology, and their products also competed with those of existing manufacturers. Therefore, when ITRI set up Vanguard, for example, the product was limited to DRAM. After the submicron plan was completed, ITRI put a plan to develop a bigger-scale deep-submicron plan, however, it encountered very strong objections from the industry, which subsequently led to the cut of the ITRI budget in 1993 by the Legislative Yuan. The industry also doubted the necessity for this plan, since at that time the R&D progress of many of the semiconductor manufacturers surpassed that of

[132] *Wessner, p.310*
[133] *Ibid, p.311*

ITRI, and the government had no need to spend huge sums to conduct duplicate research.[134]

The change in interactions with the environment was not entirely welcome in ITRI. Its management and researches find it difficult to serve both the most advanced firms, whose technological capacities sometimes rivaled that of ITRI, and more primitive companies that depended almost entirely on ITRI. Excessively ambitious projects caused local executives to complain that ITRI did not understand the practical needs of local business, but projects to develop products close to market engendered criticism that ITRI merely duplicated the efforts of the more advanced private firm, then disseminated the results to weaker companies.[135] Therefore, an aspect of trade-offs between long-term and short-term objectives emerged. In the technology service and exchange with industries, ITRI devotes around 65 percent of its services to SMEs, and around 35 percent to large companies.[136] The institute has to balance development of strategic advanced technologies with short-term incremental impacts in the situation of constant pressure to justify the worthiness of the public funds it receive. Therefore, the resource allocation between the two objectives presents a dilemma. ITRI's new organizational design provides a potential institutional approach to this issue. The dynamically linked, loosely controlled core laboratories could conduct explorative researches for radical breakthroughs under the advanced technology development programs, while the focus centers could exploit the technologies and human resources from core laboratories to probe into the emerging opportunities and create industrial impacts within shorter terms.

6.2 Political dimension of the ITRI model

The changing political environment made it impossible to sustain ITRI's position as a completely independent R&D shop. Since the end of the 1980s, when the process of democratization swept through Taiwan, regime autonomy has been gradually replaced with interest politics, which in turn broke elite consensus on developmentalism,

[134] *Huang, p.46-47*
[135] *Noble (1998), p.145*
[136] *Chen et al., p.411*

blunted state penetration into society, and forced the economic bureaucrats to engage in industrial targeting under great political pressure. The latter became a serious challenge as Taiwan's high-tech industries are believed to have generally achieved the catch-up and now are in environment where there is no clear technology guide from preceding countries. Therefore, industrial targeting became inherently risky with less guarantee in picking up the "right" strategic goal as it was the case with the semiconductors industry.[137] The controversy in development of Taiwan's biotechnology sector can serve as the most striking example in this perspective.

However, despite the negative impact, the structure was never dismantled – the government is still actively involved in technological policies and implementations. An explanation for this can be found in a number of interrelated factors. To begin with, S&T policy-making mechanism in Taiwan traditionally has been highly autonomous and based on scientific and industrial experts led by the top bureaucrats with education background in technological fields. Therefore, by the time of the political changes, the mechanism had already evolved into a combinations of top-down and bottom-up styles with a wide range of communication channels.[138] On the other hand, because of insufficient competence in S&T related issues, the Legislative Yuan and to a less extent non-governmental organizations cannot play the suitable functional role to monitor or improve policies proposed by the executive branch. Thirdly, the promotion of S&T development was greatly personified. During the initial phase of the high-tech development takeoff in the 1970s, two key figures of Li Kuo-Ting and Sun Yun-Chuan (both served as the Ministers of Economic Affairs and as the Premiers) were highly praised for their initiatives and personal interests in IC projects, the setting up of comprehensive S&T development plans, and the establishment of ITRI and HSIP.[139] In the 1990s the tradition of personalized promotion of S&T remained intact. In 1994 President Lee Teng-Hui invited Taiwanese born American chemist and Nobel Prize laureate Lee Yuan-Tze to head Academia Sinica. Gradually, Lee's influence increased and by 2000 he had became the most prominent policy-maker in S&T field, enjoying high popular reputation and

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[137] *Wu, p.997-998*
[138] *Cheng, L-P., p.5.*
[139] *Chu, pp.134-135.*

political power to gear the policies largely free from the pressure of potential rent-seekers.[140]

Finally, the two major parties – KMT and DPP – despite their political rival share a strong commitment to the idea of the state's strategic involvement in industrial technology promotion. A particularly interesting example of this is the 2001 Economic Development Advisory Conference (EDAC). The Conference was proposed by President Chen Shui-Bian in an attempt to establish bi-partisan agreement about Taiwan's future development. It generated more than three hundred points of consensus between the two parties and industry leaders on a wide range of economic issues.[141] In term of technology policy, the consensus was reached on three major aspects: first, the need to take specific actions to strengthen investments in newly emerging domestic industries; second, the creation of mechanisms to support innovative R&D in technologies and products; third, the increase in the government resource allocation for R&D budget with the target set at an annual growth of more than 12.[142] However, regardless of the similarities between the KMT and DPPs approaches toward the role of the state in Taiwan's economic development, the parties have framed a debate about the directions of development. Arguably, the debate has a deep cultural and ideological core: while the "blue" camp generally views Taiwan's economic integration with the global economy, especially with its largest trade partner – China, as key to future growth, the "green" camp prioritize improving Taiwan's domestic economy and using local sources of growth to increase global competiveness. This "technoglobalism vs technonationalism" dispute has undermined the state's formulation and implementation of technology promotion policies.

In this perspective, DPP obtained a hybrid view on ITRI's role in Taiwan's high-tech development. On the one hand, when in 2006 Premier Su Tseng-Chang, a member of then ruling DPP, visited ITRI, he praised the institute for its achievements, adding that he envied ITRI "because the researches can commit themselves to professional

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[140] *Chu, p.141*
[141] *Weiss and Thurbon, p.68*
[142] *GIO, August 26, 2001*

studies without political interference". On the other hand, DPP has long tended to see in ITRI a stronghold supporting business interests aligned with KMT. Voices within the "green" camp reportedly suggested that if the government planed to spend money on industries, the funds would be better directed toward fisheries and agriculture.[143]

The political dependence of ITRI on the state's development activities undermines the prospects of the organization. For example, ITRI's budget has not grown for more then a decade. Its leadership has put a good face on the situation by stating that lean budgets force the institute to rely on other research organizations, which is a key element of its mission. But ITRI does not grow apace with Taiwanese industries that it is tasked with supporting, and the detrimental effects of its limited budgets are evident in a number of areas. Some observers believe that ITRI tries to focus on too many technologies with too small a budget, diluting the impact of its efforts. Its low compensation levels for staff have contributed to a manpower shortage and a "talent drain" (companies based in China and Singapore reportedly are prepared to pay five times ITRI levels to lure its researchers, one factor underlying ITRI's annual average manpower turnover of 10 percent). ITRI seeks to to attract more foreign expertise to Taiwan, but the available funding is inadequate to create attractive compensation packages. Underfunding may explain what observers characterize as the "underpatenting" of ITRI's technologies, which exposes licensees to litigation.[144] Whether ITRI will be able to increase its leverage in its interaction with the state, therefore will depend on the institute's interaction with the other components of Taiwan's high-tech development system.

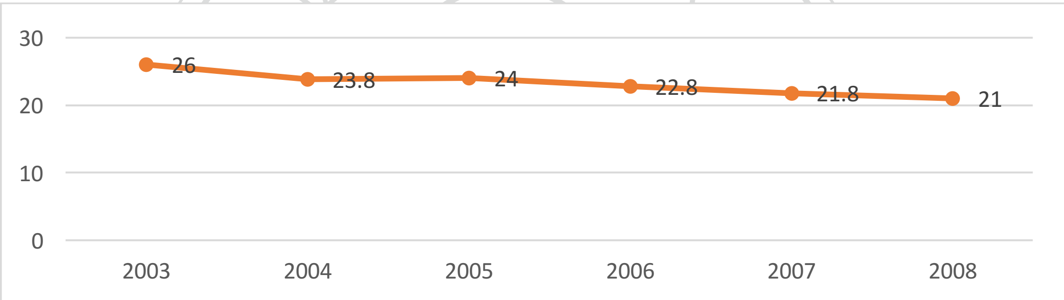
6.3 Relevance of the ITRI model at the current stage of Taiwan's high-tech development

ITRI's historic mission consists of one major element – to engage in applied research with emphasis on diffusing the research results to the manufacturing industry thus improving the technology capacity of the economy. However, the recent

143 Wessner, p.287
144 Ibid., p.308-309

macroeconomic changes call into questions the relevance of the ITRI model in the context of challenges facing Taiwan's high-tech industries at the current stage. The first change comes in a rapid fall of manufacturing industry's share of Taiwan's GDP: the number fell from 31.21 percent in 1990 to 21.70 percent in 2008, a decline of almost ten percentage points in eighteen years. By way of comparison, in Japan manufacturing's share of GDP fell by 5.83 percent (from 26.66 to 20.83 percent) over the period 1990-2003, while in South Korea the number rose by 1.48 percent, from 27.26 in 1990 to 28.74 percent in 2004. Many observers believe that decline reflects relatively low nominal value-added creation in the manufacturing sector.[145]

Figure 6-3-1. Growth of Taiwan's value-added ration in ICT manufacturing, 2003-2008 (percent)



Source: DGBAS (2009)

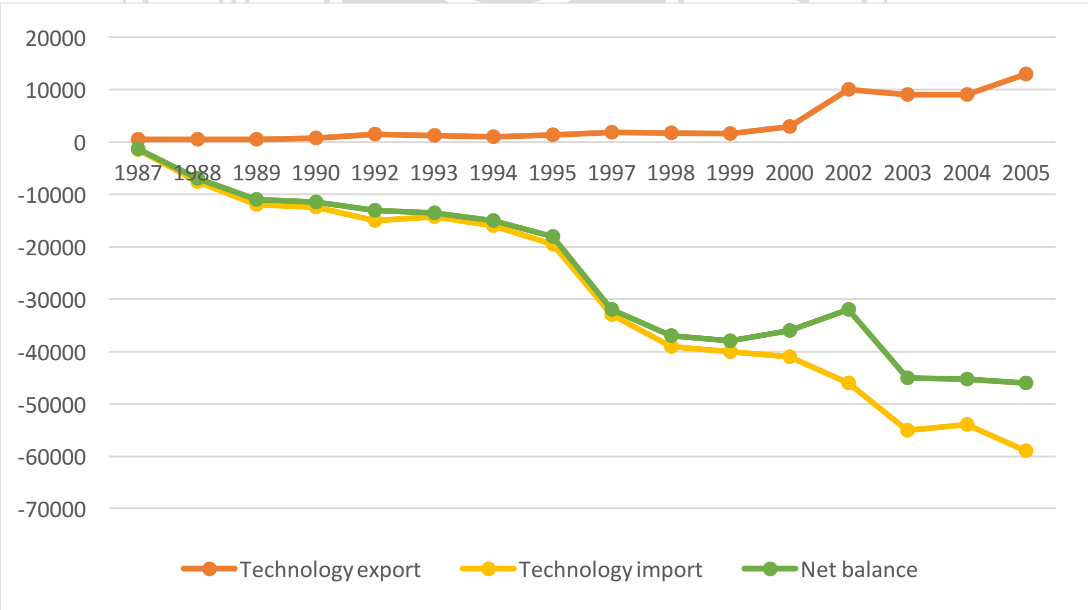
Indeed, during the 2000s ICT industry, the largest single part of Taiwan's manufacturing sector, saw its profit margins being squeezed. In 2003, the value-added ratio stood at the level of 26 percent, the number had fallen to 21 percent in 2008 (Figure 6-3-1). In fact, the trend became apparent in the late 1990s. In a study of Taiwan's high-tech industrialization, Chu analyzes the source of increases in value-added growth of Taiwanese companies over 1992-1999. The findings show that when the period is taken as a whole, one-third of the value-added growth is derived from value-added ratio effects, while the rest from sales increase. However, when analyzing the data by two periods of 1992-1995 and 1997-1999 (the data for the year of 1996 is not available), during the first period total sales effects accounted for

[145] *Wang and Ma, p.288*

around 60 percent of the growth and the rest is derived from value-added ratio effects, while during 1997-1999, total sales effects accounted for nearly 88 percent, and value-added ratio effects for 14 percent. The results suggest that Taiwan's manufacturing has been increasingly dependent on large-scale production with falling profit margins seems to be consistent with observations given by industrial specialists.[146]

Similar observation can be derived from analysis of Taiwan's technology balance of payment. Despite the strong growth in terms of high-tech economic output, the technology trade performance has been poor. Figure 6-3-2 and Tables 6-3-1 and 6-3-2 reveal the rising technology trade imbalance of Taiwan for the period 1987-2005, and the situation has been worsening since 1995. It can be seen from analysis of the import value of technology that Japan and the United States are the two major sources of technology for Taiwanese industries, but the influence of the US is rising. The export value of technology shows that China is the most important importer of Taiwanese technology (totaled 49 percent in 2005).

Figure 6-3-2. Widening gap of Taiwan's technology balance of payment, 1987-2005 (NTD million)



Source: MOEA (1997 and 2006)

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[146] *Chu, p.156-157*

Table 6-3-1. Taiwan's import value of technology by nationality, 2000-2005 (NTD million)

	Total	*Germany*	*Japan*	*US*	*Others*
2000	40,727	5,446	14,304	13,717	7,260
2002	45,246	2,243	15,938	16,404	10,661
2003	51,954	1,796	21,839	20,406	7,913
2004	52,156	2,806	21,403	20,428	7,519
2005	57,133	2,418	18,618	28,560	7,537

Source: MOEA (2006)

Table 6-3-2. Taiwan's export value of technology by nationality, 2000-2005 (NTD million)

	Total	*China*	*Thailand*	*US*	*Others*
2000	3,949	1,142	28	620	2,160
2002	11,261	4,292	198	1,318	5,452
2003	8,941	4,329	56	773	3,783
2004	8,942	4,103	39	913	3,887
2005	13,257	6,510	36	1,071	5,640

Source: MOEA (2006)

Overall, the data analyses suggest that the ITRI model as an institutionalized division of "R&D labor" between the state and business (where ITRI under the guidance of the state agencies makes decisions about which technologies industry should acquire, subsequently does most of research and development up to the level of a working prototype, and then diffuses the results to industry, which concentrates on final development and integrated design) has reached it limits by the 2000s. The model does not look sustainable as technology is a dynamic and incremental process that involves continuous advances in processes, inputs, equipment, or organizational arrangements as well as completely new approaches, new products, and new processes that can only be embodied in production facilities, rather then through a means of outside acquisition and absorption. Technology is a tacit elements and has to be adapted to specific environments that are changing constantly. Thus, at the current stage of Taiwan's high-tech industrial development it is necessary to strengthen indigenous technological capabilities through improved R&D activities and institutions building. ITRI's current institutional adaptation with the focus on generating original innovative technologies seems to be a right reflection of the changes that have happened in its environment. It remains to be seen, however, whether the organization will succeed in leveraging the risks associated with trade-offs between long- and short-term objectives as well as its status within the state.

Conclusion

The transformation of ITRI's modes of involvement into the process of Taiwan's high-tech industrialization has been complex and dynamic. This thesis proposes a framework that integrates ITRI's approaches in interacting with high-tech industries on the one hand, with the broad economic and political changes happening in its environment on the other. Using the institutional learning model, the thesis identifies the organizational learning capabilities, which in essence underlines the mechanisms of ITRI's interaction adjustment to the changes.

The historical analysis suggests three stages, in the contexts of which the institute undergoes through major organizational transformations. The transitions between the stages are different and embedded in the particular economic and political contexts.

The first transformation at the turn of the 1980s was in principle derived from a political consideration by the state top bureaucrats to improve existing institutional gaps in the mechanisms of high-tech promotion through a more centralized approach. It was this time when Taiwan's high-tech development emerged as a system with a complete institutional framework, where the state played a leading role. In the absence of significant infrastructure and private initiative, ITRI's functional role was a result of its past successful experience in running the first IC demonstration plant and, therefore, was inextricable linked with the development of the semiconductors industry. Transferring, localizing, and then spinning off private companies became the major strategies adopted by ITRI to generate impacts in relation to the industries.

The rapid growth of high-tech sector over the 1980s was accompanied by the rising technological capabilities of the business sector, which started to see in ITRI a competitor. The process of democratization that began in 1987 gradually made the state more accountable in answering the business concerns, hence ITRI was forced to readjust its focus. This time, however, the transformation of ITRI was essentially business-driven (for example, "1-to-1" and "walk-out-the-lab" initiatives had apparent roots in the vast American corporate experience of Morris Chang). In the new configuration, ITRI obtained a more delicate of role in diffusing technologies to overcome network and production failures in the center-satellite industrial organization among local firms. Accordingly, core R&D capabilities were concentrated almost solely within the public sector. Despite a rapid growth during the 1990s, this division of labor soon revealed its weaknesses as it failed to develop indigenous technological capabilities of many OEM/ODM companies, which are facing a tremendous competition from other late-comers countries, while many MNCs begun reducing their suppliers to ensure better coordination and control of products delivered to final consumers, imposing much higher contractual obligations that require the utilization of cutting-edge management, technology, delivery, and finance.

The transformation of ITRI at the current stage of Taiwan's high-tech industrial development is largely still undergoing. Now the changes are technology-driven in an environment where it is expected to fit the new role in finding emerging technology directions. ITRI is seeking to strengthen its capability in "upstream" pre-competitive R&D, to enhance the interdisciplinary character of its work, and to shift from an emphasis on the manufacture of components to development of systems, services and applications.

The context matters greatly. One of the major changes that have occurred in Taiwan's NIS over the last decade involves the role of universities, which compete and cooperate with ITRI in an increasing number of overlapping areas. Although the long-term impacts from the emerging commercialization activities of universities remain to be seen, potentially it could lead to the shift of some high-tech companies towards R&D services sourced from academia to access competences in fundamental problem-solving.

There is another aspect of importance: the balance between cutting-edge research and the provision of services that do not require the "globally optimal" level of expertise. ITRI faces a major challenge in finding a golden mean in its organizational structure to support the existing models to generate industrial impacts, while at the same time being flexible to produce innovative outcomes. Its industrial partners of different sizes have different resources and uneven absorptive capacity, therefore there is a difficulty of engaging with SMEs, even if satisfactory outcomes are achieved for large firms. Tushman and O'Reilly in their study of managing evolutionary and revolutionary changes suggested a concept of ambidextrous organizations which are capable of simultaneously pursuing both incremental and discontinuous innovation.[147] However, the resource allocation between the two objectives still presents a dilemma.

This thesis is a case study of ITRI as a governmental mechanism of technology learning for emerging technology-intensive industries in Taiwan. The analysis is based on limited resources of information and narrowed time-frame, therefore the findings may not be sufficient to justify the external validity to other R&D agencies. However, the proposed framework could provide a basis for studying organizational changes in an environment where major institutional transformations take place, especially for ITRI-like organizations in Taiwan.

What is a source of effective institutional learning of ITRI? There are some indications, that during the high-tech industrial takeoff in Taiwan, the state top bureaucrats did play a positive role in facilitating consistent institutional learning of it. The same cannot be said about the Institute for Information Industry (III), a mirror reflection of ITRI in the software sector. Unlike ITRI, established in 1979 III from the beginning evolved to a position of a competitor to the private industry. III never managed to take a contributing leadership position in software technology development projects in the same way ITRI did in hardware. With the decline of developmental state in Taiwan, the model carries even greater risks, since it remains to be seen whether the mechanisms of democratic control could effectively assess new initiatives by the government.

[147] *Tushman and O'Reilly, p.11*

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