CHAPTER 5 INNOVATION SURVEY OF TAIWAN'S BIOTECHNOLOGY INDUSTRY

5.1. Introduction

This chapter applies the concept of ***National Innovation Systems*** (NIS) to designing an innovation survey to investigate the firms in Taiwan's biotechnology innovation systems. The principal objectives of the survey are as follow.

(1) To estimate the economic scope and size of Taiwan's biotechnology industry;

(2) To assess the characteristics and current status of Taiwan's biotechnology industry;

(3) To understand the innovative behavior and performance of biotech firms in Taiwan;

(4) To identify firms' perceptions of barriers to collaborative R&D, and of impediments to the development in the biotechnology industry;

(5) To examine Taiwan's biotechnology innovation systems and to propose a better science and technology (S&T) policy for Taiwan's biotechnology industry.

5.2. Definition and Scope of Biotechnology

Biotechnology in the survey is defined as the application of biological processes to solve problems, conduct research, and create goods and services. Under this definition, biotechnology includes a diverse collection of technologies that manipulate cellular, subcellular, or molecular components in living things to make products, discover new knowledge about the molecular and genetic bases of life, or modify plants, animals, and microorganisms to carry desired traits for commercial purposes. In short, the biotechnology is cellular and genetic techniques that manipulate biological architecture for applications in various scientific fields and industries such

as medicine, medical devices, animal health, agriculture, aquaculture, food, environment management, and technical services[1] (Table 5.1).

Table 5.1: The Scope of Biotechnology Applications for the Survey

Category	Examples
Medicine	Biopharmaceuticals Therapeutics Diagnostics Drug design and delivery Drug discovery Cell and tissue engineering Gene therapy Regenerative medicine Alternative medicine Traditional Chinese Medicine (TCM), botanical drugs, herbal medicine Vaccines Antibiotics
Medical Devices	Bio-chips (e.g. Protein-chips) Bio-sensors Gene probes Reagents, kits, assays Biologicals Medical devices Medical instrumentation Medical supplies Homecare (e.g. Diabetes monitoring)
Industrial Biotechnology	Specialty chemicals (e.g. Amino acids) Bio-processing (e.g. Bacteria culture) Bio-based lubricants and functional fluids Renewable alternative fiber papers and packaging Plant-based plastics, polymers and films Wood-based composite materials Fermentation Enzymes Catalysts Flavors or fragrances Cosmetics (e.g. Collagen) Phytochemicals Neutraceuticals Medical food Functional foods Supplements or vitamins Food processing

[1] The manipulation of cellular and sub-cellular building blocks could be both ancient (fermentation and brewing) and current (recombining genes, and using computers to analyze nucleotide sequences and protein structures to pinpoint drug targets). The definition here is similar to that in ***A Survey of the Use of Biotechnology in U.S. Industry*** (U.S. Department of Commerce, 2003).

Agricultural Biotechnology	Bio-fertilizers Bio-herbicides Tissue culture Seeds and plant breeding Genetically modified products Transgenic plants Livestock Transgenic animals Veterinary products Animal vaccines Aquaculture
Environmental Biotechnology	Bio-based energy (e.g. Microbiologically enhanced petroleum) Bio-based waste treatment Bio-based pollution prevention Natural resource recovery (e.g. Mineral recovery) Bio-processing Bioremediation Phytoremediation Bio-pulping Bio-bleaching Bio-filtration Biodesulphurization Biomaterials Biomass conversion Enzymes Marine microbial Terrestrial microbial
Enabling Technologies and R&D Services	DNA, peptides, or proteins sequencing DNA, peptides, or proteins synthesis DNA markers Polymerase Chain Reaction (PCR) amplification Bio-informatics Single-Nucleotide Polymorphisms (SNPs) Genomics Proteomics Cellomics / Cell receptors or signaling Pharmacogenomics High throughput screening Combinatorial chemistry 3-D molecular modeling Cloning / Culturing of cells, tissues, embryos Stem cells Extractions, purifications, separations Clinical tests Clinical trial management Contracted research (CRO) Contracted manufacturing (CMO)

Sources: 1. U.S. Department of Commerce (2003), ***A Survey of the Use of Biotechnology in U.S. Industry***.

2. Burrill & Company (2003), ***Biotech 2003***.

3. IDB, MOEA (2002), ***White Paper for Biotechnology Industry in Taiwan 2003***.

4. TIER (2003), ***The Scope and Classification of the Biotechnology Industry***.

5.3. Methodology

In Taiwan, biotech-related activities are being pursued in a wide variety of industries, so firms involved in biotechnology are not classified as a distinct industry within the national standard industrial classification. One of the reasons is that the application and development of "modern" biotechnology is relatively recent, and incorporation into national statistical accounts takes some time. More importantly, as biotechnology is applied to a widening array of industrial applications, developing a single classification category for firms engaged in biotechnology-related activity is proving to be complex and difficult[2].

The definition of biotechnology has never reached consensus among countries, or even within a country. The definition adopted from different national and international sources have been heterogeneous. The lack of a general and commonly accepted definition of biotechnology affects the reliability and comparability of official statistics, making any measurement extremely difficult. In addition to different coverages of biotechnology across national surveys, the lack of standardized survey procedures and consistent measurement prevents the existence of comparable indicators. So the research here had to redefine the survey population and to design a new questionnaire for the objectives mentioned above, by investigating the firms in the biotech-related industries in Taiwan. The analysis below, based on the survey responses received, is to describe the firms' innovation behavior and performance at the aggregate level, as well as to assess the characteristics of Taiwan's biotechnology

[2] In the U.S., firms involved in biotechnology are not classified as a distinct industry within the North American Industry Classification System (NAICS) for the same reasons. According to ***A Survey of the Use of Biotechnology in U.S. Industry*** (U.S. Department of Commerce, 2003), the survey respondents identified more than 60 four-digit NAICS categories, mostly "medical substances and devices" (NAICS category 3254) or "scientific R&D services" (5417), but as diverse as "paints, coating and adhesives" (3255), "semiconductor and related device manufacture" (3344), and "waste management and remediation services" (5629).

industry, which may not be comparable to other studies[3].

The large-scale survey was carried out by Taiwan Institute of Economic Research (TIER) during the period between May and July in 2003 in Taiwan to collect basic data of biotech firms, such as business, investment, capital, revenues, R&D expenditures and employment, as well as their innovative activities, including innovation strategies and collaborative R&D objectives, types, frequencies, and performance[4]. I, on behalf of TIER, was the coordinator and single researcher for the research project. I designed the survey questionnaire and analyzed the data myself. A copy of the survey questionnaire in English is included in Appendix 2.

5.4. Survey Population

In Taiwan, biotech-related products and processes are developed and applied by research and academic institutions in life sciences, as well as companies in the industries such as medicine, medical devices, animal health, agriculture, aquaculture, food, environment management, and technical services. The initial survey population of 1,607 companies was made up of the firms included in one of the sources obtained from biotechnology directories, databases and websites, public traded lists, 11 industrial associations[5], 41 incubators affiliated to universities and

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[3] Such variation usually occurs because methodological differences in survey design, survey population, and interpretation result in different data and conclusions. Quantitative differences may also arise because of the way questions are asked, say terminology.

[4] The research project was entrusted by Industrial Development Bureau, Ministry of Economic Affairs, in 2003 (IDB project number 9200010069).

[5] The survey population included the members of the following associations in Taiwan.

(1) Development Center for Biotechnology (179 members)
(2) Bioweb, http://www.bioweb.com.tw/ (712 members)
(3) Taiwan Pharmaceutical Industry Association (293 members)
(4) Taiwan Medical Devices and Supplies Industry Association (215 members)

science parks in Taiwan, which appeared to meet the official definition of biotechnology in a broad sense. The survey questionnaire was mailed to all of these companies above in May 2003, excluding government organizations, academia and research institutions from the study. Responses had been received from more than half of companies surveyed by the end of July 2003. Of these, **258** respondents identified themselves as biotech firms and provided sufficient data for analysis[6].

All of the survey data were reviewed by the Biotechnology and Pharmaceutical Industries Program Office (BPIPO), and Industrial Development Bureau (IDB), Ministry of Economic Affairs (MOEA) in August 2003[7]. **165** of 258 respondents were considered to have *significant* R&D activities in biotechnology in 2002, in terms of either workforce with biotechnology-related responsibilities or R&D expenditures[8] (Table 5.2). The analysis below is based on survey responses from the **165** companies confirming that they were engaged in biotechnology research, create biotechnology products or research tools, or use biotechnology processes in their

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(5) Taiwan Agricultural Engineering Industry Association (35 members)
(6) Taiwan Plant Preservation Industry Association (51 members)
(7) Seeds and Plant Breeding Association (55 members)
(8) Central Livestock Association (56 members)
(9) China Animal Husbandry Association (14 members)
(10) Taiwan Animal Drugs Industry Association (73 members)
(11) R.O.C. Aquaculture Association (54 members)

[6] The methodology here is similar to that in ***A Survey of the Use of Biotechnology in U.S. Industry*** (U.S. Department of Commerce, 2003).

[7] In some cases, those who were standard biotech firms in every sense refused to reply. In other cases, those who claimed to be biotech companies did not use any biotechnology in their manufacturing processes or R&D activities. Every effort in the research was made to ensure that the final results could reflect the inclusion of appropriate companies.

[8] Recipients of the survey were asked to identify themselves as biotech companies and to confirm that their company was engaged in biotech-related activities in the beginning of the survey questionnaire. Then they were asked to provide the details of R&D expenditures and research staffs. Of 258 respondents, 165 were either *with R&D expenditures as a percentage of revenues more than 5% in 2002*, or *with employees that have biotechnology-related responsibilities as a percentage of workforces more than 10%*, which were considered to have '*significant' R&D activities* in biotechnology in 2002.

manufacturing – either as one of several business lines or as their sole business[9]. A list of the 165 respondents in English is included in Appendix 3.

Table 5.2: R&D Expenditures as a Percentage of Revenues, for all Respondents

R&D Expenditures as a Percentage of Revenues	Number of Firms	Share	Cumulative Number of Firms
0% ~5%	73	*39.0%*	73
5% ~10%	37	*19.8%*	110
10% ~15%	9	*4.8%*	119
15% ~20%	14	*7.5%*	133
20% ~25%	2	*1.1%*	135
25%+ ~50%	15	*8.0%*	150
50%+ ~75%	6	*3.2%*	156
75%+ ~100%	4	*2.1%*	160
100%+	27	*14.4%*	187
Total	**187**	*100.0%*	

Note: Derived from the 187 of the respondents reporting both R&D expenditures and revenues in 2002.

After reviewed by BPIPO, IDB, MOEA, of them, 165 respondents were considered to have *significant* R&D activities in biotechnology in 2002, in terms of either workforce with biotechnology-related responsibilities or R&D expenditures *(Please see footnotes 7 and 8)*.

Source: Based on the 258 survey responses (IDB project number 9200010069, 2003).

5.5. Business Characteristics of the Respondents

Firms engaged in biotechnology activities in Taiwan vary greatly in size and scope. At one end of the spectrum, there are small, dedicated biotech firms that focus primarily on R&D or production. At the other end of the spectrum, there are a number of large, diversified companies in traditional manufacturing sectors, with abundant in-house resources and well-established production and distribution systems. They devote only a fraction of their resources to biotech-related product development or investment activities. Therefore, there are great differences in business characteristics between the two types of the respondents.

[9] The number of firms, 165, is adopted by ***White Paper for Biotechnology Industry in Taiwan 2003*** (IDB, MOEA, 2002), as official data of Taiwan's biotechnology industry in the strict sense.

To gain a better understanding of so-called biotech firms in Taiwan, based on the 165 responses, it is found that their principal capital and revenues in 2002 are *US$5.1 million* and *US$4.6 million* on average respectively, much smaller than those for all of the 258 respondents. But average R&D expenditures are *US$0.5 million*, equivalent to that for the 258 respondents. Consequently, R&D intensity, measured by R&D expenditures as a percentage of revenues, is *11%*, much higher than 3% for all of the respondents. Among them, 27 companies reported that the R&D expenditures exceeded the revenues in 2002, particularly (Table 5.3).

Biotechnology-related occupations are knowledge-based, and most biotechnology-related employees are highly educated. It is found, therefore, that the 165 companies have as many employees with post-graduate degrees (including Ph.D. and Master Degrees) on average as the 258 respondents. They had a larger biotech-related technical workforce on average, although they reported *40* employees on average, fewer than 110 for the 258 respondents (Table 5.4).

Furthermore, based on the 165 responses, it is estimated that the revenues and R&D expenses of Taiwan's biotechnology industry were *US$758.7 million* and *US$83.6 million* respectively in 2002. There were *6,609* employees, and *1,842* of them with biotechnology-related responsibilities in the industry as defined above[10] (Tables 5.3 and 5.4).

[10] The estimates based on the survey here, say the revenues NT$ 25 billion and the employees 6,609, are adopted by ***White Paper for Biotechnology Industry in Taiwan 2003*** (IDB, MOEA, 2002), as official data of Taiwan's biotechnology industry in the strict sense. It is believed to be the best estimates for the moment, although it is not possible to say that the survey responses are for the whole of Taiwan's biotechnology industry anyway.

Table 5.3: Financial Data for the Survey Respondents, 2002*

	Principal Capital ($ 000)	Revenues ($ 000)	R&D Expenditures ($ 000)	R&D Intensity**
For All Respondents (258 Firms)				
Total for firms providing details	3,318,756	4,343,521	123,629	
Average	***13,382***	***20,016***	***597***	***3.0%***
Estimate for 258 firms +	**3,452,576**	**5,164,186**	**154,089**	
For 165 Biotech Firms* **				
Total for firms providing details	812,666	625,394	68,884	
Average	***5,111***	***4,598***	***506***	***11.0%***
Estimate for 165 firms ++	**843,333**	**758,750**	**83,572**	

Note: * The figures of the table have been converted by NTD/USD = 33. Unit: $000 = US$ thousand.

** R&D intensity is measured by R&D expenditures as a percentage of revenues.

*** The 165 of 258 respondents were considered to have R&D activities in biotechnology in 2002 by the Biotechnology and Pharmaceutical Industries Program Office (BPIPO), and Industrial Development Bureau (IDB), Ministry of Economic Affairs (MOEA).

+ Estimate for 258 firms is the average multiplied by 258.

++ Estimate for 165 firms is the average multiplied by 165.

Source: Based on the 258 survey responses (IDB project number 9200010069, 2003).

Table 5.4: Human Resources for the Survey Respondents

	Number of Employees	Employees with Ph.D. degree	Employees with Master degree	Biotech-related Technical Workforce
For All Respondents (258 Firms)				
Total for firms providing details	27,166	355	1,773	2,283
Average	***110***	***2***	***8***	***9***
Estimate for 258 firms +	**28,491**	**467**	**2,051**	**2,444**
For 165 Biotech Firms*				
Total for firms providing details	6,609	273	946	1,842
Average	***40***	***2***	***7***	***11***
Estimate for 165 firms ++	**6,609**	**349**	**1,076**	**1,842**

Note: * The 165 of 258 respondents were considered to have R&D activities in biotechnology in 2002 by the Biotechnology and Pharmaceutical Industries Program Office (BPIPO), and Industrial Development Bureau (IDB), Ministry of Economic Affairs (MOEA).

+ Estimate for 258 firms is the average multiplied by 258.

++ Estimate for 165 firms is the average multiplied by 165.

Source: Based on the 258 survey responses (IDB project number 9200010069, 2003).

5.6. Variety of Applications

All respondents were asked to indicate up to six major items of biotechnology activities they are engaged in the bio-related industries. They were classified into different application categories according to their answers. Some of the biotech firms can be considered in several different areas, resulting in multiple application categories for a single respondent. For example, a TCM company might have indicated that it performs research in medicine and produces functional food[11] as well. In such a case, the response would be reported and analyzed in both application categories. Furthermore, firms were not asked to segment their revenues, employment, and related information, and could indicate multiple applications for their biotech activities. Therefore, the statistics below presented by application category should only be interpreted as data for all firms that selected the application as one of their businesses.

Based on the survey respondents, *74* of the 165 companies selected "*Medicine*" as their application focus, *46* chose "*Medical Devices*", *51* chose "*Industrial Biotechnology*", *38* chose "*Agricultural Biotechnology*" related activities, *13* chose "*Environmental Biotechnology*" related activities, and *31* chose "*Enabling Technologies and R&D Services*" related activities. Because many respondents indicated that they work in several areas of biotech-related industries, application-specific data cannot be summed to obtain estimates of total biotech-related revenues, employment, and other quantitative data due to double counting[12] (Table 5.5).

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[11] It can be changed as nutraceuticals, including herbs, nutrition or dietary supplements.

[12] The methodology here is similar to that in ***A Survey of the Use of Biotechnology in U.S. Industry*** (U.S. Department of Commerce, 2003).

Table 5.5: Average Size Analysis by Application Category*

Application Category	Number of Firms**	Employees Average	Principal Capital Average ($ 000)	Revenues Average ($ 000)	R&D Expenditures Average ($ 000)
Medicine	*74*	50	7,762	5,296	785
Medical Devices	*46*	37	4,789	2,337	479
Industrial Biotechnology	*51*	36	4,548	5,206	398
Agricultural Biotechnology	*38*	29	2,215	2,330	194
Environmental Biotechnology	*13*	22	2,325	1,318	231
Enabling Technologies and R&D Services	*31*	40	7,875	1,432	490

Note: * The figures of the table have been converted by NTD/USD = 33. Unit: $000 = US$ thousand.

** In the survey, all respondents were asked to indicate up to six major items of biotechnology activities in bio-related industries, and thus classified into at least one of different application categories. So some of the biotech firms can be considered in several different areas, resulting in multiple application categories for a single respondent.

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

5.7. Size Analysis by Application Category

Companies engaged in different biotech applications have somewhat different business characteristics. What follows below therefore describes average size of the 165 companies by application category. In terms of the number of **employees**, average size of the 74 companies which selected "*Medicine*" as their application focus is *50*, that of "*Enabling Technologies and R&D Services*" is *40*, that of "*Medical Devices*" is *37*, that of "*Industrial Biotechnology*" is *36*, that of "*Agricultural Biotechnology*" is *29*, and that of "*Environmental Biotechnology*" is *22*. Most of them are typical small-and-medium sized firms (Table 5.5).

Average **principal capital** of the 31 companies which selected "*Enabling Technologies and R&D Services*" as their application focus is *US$7.9 million*, that of "*Medicine*" is *US$7.8 million*, that of "*Medical Devices*" is *US$4.8 million*, that of "*Industrial Biotechnology*" is *US$4.5 million*, that of "*Environmental Biotechnology*" is *US$2.3 million*, and that of "*Agricultural Biotechnology*" is *US$2.2 million* (Table 5.5).

Average **revenues** of the 74 companies which selected "*Medicine*" as their application focus is *US$5.3 million*, that of "*Industrial Biotechnology*" is *US$5.2 million*, that of "*Medical Devices*" is *US$2.3 million*, that of "*Agricultural Biotechnology*" is *US$2.3 million*, that of "*Enabling Technologies and R&D Services*" is *US$1.4 million*, and that of "*Environmental Biotechnology*" is *US$1.3 million* (Table 5.5).

For **labor productivity**, measured by revenues per employee, that of the companies which selected "*Industrial Biotechnology*" as their application focus is as much as *US$144.6 thousand*, that of "*Medicine*" is *US$105.9 thousand*, that of "*Agricultural Biotechnology*" is *US$80.3 thousand*, that of "*Medical Devices*" is *US$63.2 thousand*, that of "*Environmental Biotechnology*" is *US$59.9 thousand*, and that of "*Enabling Technologies and R&D Services*" is *US$35.8 thousand* (Table 5.6).

Average **R&D expenditures** of the companies which selected "*Medicine*" as their application focus is *US$785 thousand*, that of "*Enabling Technologies and R&D Services*" is *US$490 thousand*, that of "*Medical Devices*" is *US$479 thousand*, that of "*Industrial Biotechnology*" is *US$398 thousand*, that of "*Environmental*

Biotechnology" is *US$231 thousand*, and that of "*Agricultural Biotechnology*" is *US$194 thousand* (Table 5.5).

For **R&D intensity**, measured by R&D expenditures as a percentage of revenues, that of the companies which selected "*Enabling Technologies and R&D Services*" as their application focus is *34.2%*, that of "*Medical Devices*" is *20.5%*, that of "*Environmental Biotechnology*" is *17.5%*, that of "*Medicine*" is *14.8%*, that of "*Agricultural Biotechnology*" is *8.3%*, and that of "*Industrial Biotechnology*" is *7.7%* (Table 5.6).

Table 5.6: Productivity and Intensity Analysis by Application Category*

Application Category	Revenues / Employees ($ 000)	Operating Income / Revenues**	Principal Capital / Employees ($ 000)	Principal Capital / Revenues	R&D Expenditures / Employees ($ 000)	R&D Expenditures / Revenues
Medicine	105.9	*28.7%*	155.2	*146.6%*	15.7	*14.8%*
Medical Devices	63.2	*24.9%*	129.4	*204.9%*	12.9	*20.5%*
Industrial Biotechnology	144.6	*29.0%*	126.3	*87.4%*	11.1	*7.7%*
Agricultural Biotechnology	80.3	*23.8%*	76.4	*95.1%*	6.7	*8.3%*
Environmental Biotechnology	59.9	*25.3%*	105.7	*176.4%*	10.5	*17.5%*
Enabling Technologies and R&D Services	35.8	*22.8%*	196.9	*549.9%*	12.3	*34.2%*

Note: * The figures of the table have been converted by NTD/USD = 33. Unit: $000 = US$ thousand.

****** Derived from the respondents providing both operating income and revenues.

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

5.8. Background of Respondents

Of the 165 survey respondents that reported establishment dates, 115 companies (about 70%) have been established since *1996*. It appears that the rate of growth in the number of companies engaged in biotechnology in Taiwan has shown a upward trend during the past decade, if survey data are indicative of national trends (Table 5.7). In addition, 60 of the 165 companies are located in Taipei.

Table 5.7: Establishment Dates for Respondents

Year Established	Number of Firms	Percentage of Total
Before 1981	14	*8.5%*
1981-1985	6	*3.6%*
1986-1990	5	*3.0%*
1991-1995	18	*10.9%*
1996-2000	79	*47.9%*
After 2000	36	*21.8%*
N.A.	7	*4.2%*
Total	**165**	***100.0%***

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Nearly half of these 165 responses reported that *domestic entrepreneur* was one of the founders when the companies were established. Noticeably, 27 firms of them indicated that one of their company founders was *overseas Taiwanese scientist or professional*. However, *professors or scientists from universities* have not been playing as a leading role in creating biotech companies in Taiwan yet as in the U.S. (Table 5.8).

Table 5.8: Founders of Establishment for Respondents

Founders	Number of Firms*	Percentage of Total
Domestic Entrepreneurs	116	*49.4%*
Professors or Scientists from Domestic Universities	20	*8.5%*
Research Fellows from Domestic Research Institutes	29	*12.3%*
Students from Domestic Universities or Colleges	31	*13.2%*
Overseas Taiwanese Scientists or Professionals	27	*11.5%*
Foreigners	9	*3.8%*
Other	3	*1.3%*

Note: * Number of firms indicating this item (multiple answers).
Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

137 of the 165 respondents reported that *domestic angel investor* was one of the funding sources when the companies were established. And *domestic enterprises* account for 24% of total of responses (selected by 54 firms) indicating for initial funding sources. It appears, however, that *Taiwanese venture capital firms* (selected by as few as 14 firms) did not play as an active role in financing local biotech companies as they did in the U.S.[13] (Table 5.9)

Table 5.9: Funding Sources of Establishment for Respondents

Funding Sources of Establishment	Number of Firms*	Percentage of Total
Domestic Enterprises	54	*24.3%*
Foreign Enterprises	4	*1.8%*
Domestic Venture Capital Firms	14	*6.3%*
Foreign Venture Capital Firms	1	*0.5%*
Domestic Angel Investors	137	*61.7%*
Foreign Angel Investors	3	*1.4%*
Taiwan Government Funds	7	*3.2%*
Other	2	*0.9%*

Note: * Number of firms indicating this item (multiple answers).
Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

[13] There are over 200 venture capital firms in Taiwan. Among them, China Development Industrial Bank (CDIB), particularly, was the seventh biggest biotech investor in the world, with total unrealized profit of NT$1.7 billion, according to VC DealWatch (28 January 2002).

The 165 respondents funded themselves the way the traditional manufacturing sectors did, although being considered to have significant R&D activities in biotechnology in 2002. More than 70% of the responses indicated that *production and product sales* were still primary sources of revenues. In contrast, *contracted research* and *licensing-out technologies* were selected by 32 and 26 biotech firms respectively as their sources of revenues. For Taiwanese investors, in-house revenues are considered to be the most reliable funding sources for R&D activities in Taiwan (Table 5.10).

Table 5.10: Sources of Revenues for Respondents

Sources of Revenues	Number of Firms*	Percentage of Total
Licensing-out Technologies	26	*8.4%*
Contracted Research	32	*10.3%*
Research Services	17	*5.5%*
Production	97	*31.3%*
Product Sales	123	*39.7%*
Capital Gains	2	*0.6%*
Other	13	*4.2%*

Note: * Number of firms indicating this item (multiple answers).

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

5.9. Employment Structure and Strategy

Most of the respondents indicated that their workforces were mainly made up of *graduates from universities or colleges in Taiwan*. But for skilled workers and professionals, 71 of the 165 firms had *recruited talents from research institutes in Taiwan*. Moreover, 27 of them had *recruited overseas Taiwanese scientists* (Table 5.11).

Table 5.11: Sources of Skilled Workers and Professionals for Respondents

Research Staffs	Number of Firms*	Percentage of Total
Recruit Graduates from Universities or Colleges in Taiwan	129	*44.6%*
Recruit Talents from Other Companies in Taiwan	34	*11.8%*
Recruit Talents from Research Institutes in Taiwan	71	*24.6%*
Recruit Overseas Taiwanese Scientists	27	*9.3%*
Recruit Foreigners	10	*3.5%*
Other	18	*6.2%*

Note: * Number of firms indicating this item (multiple answers).

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

For most of Taiwanese biotech firms, *government training programs* (selected by 80 respondents), *R&D collaborations* (50), *outsourcing training* (47), and *academic training programs* (37) were important ways to train their workers, besides *in-house training* (136) (Table 5.12).

Table 5.12: Training Programs of Workers for Respondents

Training Programs	Number of Firms*	Percentage of Total
In-house Training	136	*38.3%*
Outsourcing Training	47	*13.2%*
Government Training Programs	80	*22.5%*
Academic Training Programs	37	*10.4%*
R&D Collaborations	50	*14.1%*
Other	5	*1.4%*

Note: * Number of firms indicating this item (multiple answers).

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

5.10. Expenditure Structure

Most of the 165 respondents indicated that *labor cost*, *materials*, *equipments and facilities* were the major expenditures for R&D activities. *Technology licensing-in fees* accounted for only a fraction of sales, and many of them even did not have any

technology licensed in at all. It appears, furthermore, that technology licensing or trading of Taiwan's biotechnology industry has not been as active across borders as expected (Tables 5.13, 5.14, and 5.15).

Table 5.13: Expenditures of R&D Activities for Respondents

R&D Expenditures	Number of Firms*	Percentage of Total
Licensing-in Fees	43	*10.3%*
Labor Cost	121	*29.1%*
Materials	96	*23.1%*
Equipments and Facilities	102	*24.5%*
R&D Collaborations	37	*8.9%*
Rents	14	*3.4%*
Other	3	*0.7%*

Note: * Number of firms indicating this item (multiple answers).
Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Table 5.14: Technology Licensing-in Fees as a Percentage of Sales for Respondents

Licensing-in Fees / Sales	Number of Firms*	Percentage of Total
More than 30%	11	*6.9%*
20%+~30%	7	*4.4%*
10%+~20%	17	*10.6%*
0%+~10%	59	*36.9%*
Zero	66	*41.3%*

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Table 5.15: Primary Source of Licensing-in Technologies for Respondents

Sources of Technologies Licensing-in	Number of Firms	Percentage of Total
U.S.	29	*19.3%*
European Nations	9	*6.0%*
Japan	12	*8.0%*
Taiwan	68	*45.3%*
Rest of World	32	*21.3%*

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

5.11. R&D Activities and Strategies

As ***Absorptive Capacity*** emphasized, it is found that *in-house R&D* was the primary source of key technologies for most of Taiwan's biotech firms. So they depended heavily on *non-patented technologies developed by the company* or *patents of the company's own*. However, *establishing R&D collaborations with other organizations* was the second most type of R&D activities (selected by as many as 92 firms), and consequently, *using the results from research collaborations with other in Taiwan* was also an important source of key technologies (Tables 5.16 and 5.17).

Table 5.16: Type of R&D Activities for Respondents

R&D Activities	Number of Firms*	Percentage of Total
In-house R&D	146	*44.4%*
R&D Spin-out or Establishing Subsidiaries	13	*4.0%*
Establishing R&D Collaborations with Other Organizations	92	*28.0%*
R&D Outsourcing	47	*14.3%*
Technology Licensing or Trading	31	*9.4%*
Other	0	*0.0%*

Note: * Number of firms indicating this item (multiple answers).
Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Table 5.17: Sources of Key Technologies for Respondents

Key Technologies	Number of Firms*	Percentage of Total
Free or Expired Patents	15	*4.3%*
Non-patented Technologies Developed by the Company	96	*27.6%*
Patents of the Company's Own	75	*21.6%*
Licensing-in Technologies from the other Companies in Taiwan	8	*2.3%*
Licensing-in Technologies from Research Institutes in Taiwan	36	*10.3%*
Using the Results from Research Collaborations with Other in Taiwan	60	*17.2%*
Crossing Licensing Technologies with Other	6	*1.7%*
Using the Results from Research Collaborations with Foreigners	21	*6.0%*
Licensing-in Technologies from Abroad	26	*7.5%*
Other	5	*1.4%*

Note: * Number of firms indicating this item (multiple answers).
Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Collaborative R&D prevailed in Taiwan's biotechnology industry as shown above. Based on the respondents having other than in-house R&D activities, furthermore, *speeding up R&D process*, *access to complementary capabilities or specialized skills*, *access to state-of-the-art facilities* were the major motives for the collaborative R&D. It is important to notice that as many as 104 firms had *cooperated with academia and research institutes in Taiwan.* Besides, 62 firms indicated to have *research projects partially subsidized by Taiwan government*, and 29 of them had *at least one R&D project funded by Taiwan government each year* (Tables 5.18, 5.19, 5.20, and 5.21).

Table 5.18: Motives of the Collaborative R&D for Respondents

Motives of Collaborative R&D	Number of Firms*	Percentage of Total
Sharing of Risk for R&D	20	*6.4%*
Sharing of Cost for R&D	30	*9.6%*
Speeding up R&D Process	72	*23.2%*
Access to Complementary Capabilities or Specialized Skills	54	*17.4%*
Access to State-of-the-art Facilities	54	*17.4%*
Access to Market and Technology Information	38	*12.2%*
Building up Connections or Channels	41	*13.2%*
Other	2	*0.6%*

Note: * Number of firms indicating this item (multiple answers).

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Table 5.19: Typology of Partners for the Collaborative R&D for Respondents

Typology of Partners for Collaborative R&D	Number of Firms*	Percentage of Total
Competitors or Other Firms in Taiwan	19	*6.6%*
Customers or Suppliers in Taiwan	30	*10.4%*
Academia and Research Institutes in Taiwan	104	*36.1%*
Competitors or Other Firms Abroad	16	*5.6%*
Customers or Suppliers Abroad	14	*4.9%*
Academia and Research Institutes Abroad	18	*6.3%*
Research Projects Initiated by Taiwan Government	24	*8.3%*
Research Projects Subsidized by Taiwan Government	62	*21.5%*
Other	1	*0.3%*

Note: * Number of firms indicating this item (multiple answers).

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Table 5.20: Frequency of R&D Projects Funded by Taiwan Government for Respondents

R&D Projects Funded by Government	Number of Firms	Percentage of Total
Three Projects or More Each Year	6	*5.8%*
One or Two Projects Each Year	23	*22.3%*
Having Projects Funded but Not for Each Year	55	*53.4%*
No Project Funded Ever	19	*18.4%*

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Table 5.21: Expenditures for Projects Funded by Taiwan Government for Respondents, 2002

Expenditures for Projects Funded by Government*	Number of Firms	Percentage of Total
More than $606,060	9	*8.9%*
$303,030 - $606,060	13	*12.9%*
$151,515 - $303,030	9	*8.9%*
$30,303 - $151,515	26	*25.7%*
Less than $30,303	15	*14.9%*
Zero	29	*28.7%*

Note: * The figures of the table have been converted by NTD/USD = 33. $: US dollar.

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

For collaborative R&D, *different views on intellectual property rights*[14], *different views on expenditures or shares, high mobility of participants or research staffs* were identified as the barriers to the collaborative R&D (Table 5.22). In addition to the transaction cost for collaborative R&D above, *access to R&D projects subsidized by Taiwan government* was considered impossible by 34 respondents. Most of the firms (55) were *not able to have projects funded by Taiwan government each year*, and even worse, at least 19 firms had *never had a project funded* by the government (Table 5.20).

Table 5.22: Barriers to the Collaborative R&D for Respondents

Barriers to Collaborative R&D	Number of Firms*	Percentage of Total
Different Views on Intellectual Property Rights	35	*13.9%*
Different Views on Licensing Revenues or Loyalties	19	*7.5%*
Different Views on Expenditures or Shares	27	*10.7%*
Different Views on Human Resources or Inputs	10	*4.0%*
Different Views on Topics	16	*6.3%*
Different Views on Priorities or Processes	18	*7.1%*
Communications with Participants or Research Staffs	9	*3.6%*
Low Incentive of Participants or Research Staffs	13	*5.2%*
High Mobility of Participants or Research Staffs	26	*10.3%*
Forming R&D Collaboration Agreements	18	*7.1%*
Insufficient Government Funding for R&D	15	*6.0%*
Antiquated Rules and Regulations	12	*4.8%*
No Access to R&D Projects Subsidized by Government	34	*13.5%*

Note: * Number of firms indicating this item (multiple answers).

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

[14] In Taiwan, the main topics of legal framework for collaborative R&D are as follow:
(1) Property rights in the patents achieved through collaboration;
(2) Solving contractual problems in licensing concession;
(3) Authorships and rights of publications for research findings.

5.12. R&D Performances

The contributions of biotechnology R&D activities are quite diversified. Based on the survey responses, most of the R&D activities resulted in *developing new technologies* and *upgrading quality of products*. Most importantly, 59 firms confirmed to have *increasing revenues or profits*, which makes economic sense (Table 5.23).

Table 5.23: Contributions of R&D Activities for Respondents

Contributions of R&D Activities	Number of Firms*	Percentage of Total
Reducing Labor Costs	11	*3.0%*
Expanding Production Capacity	18	*4.9%*
Extending Product Pipeline	49	*13.4%*
Upgrading Quality of Products	80	*21.8%*
Developing New Technologies	83	*22.6%*
Increasing Number of Patent Filings	53	*14.4%*
Increasing Revenues or Profits	59	*16.1%*
Insignificant Results	14	*3.8%*

Note: * Number of firms indicating this item (multiple answers).

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Although 53 firms indicated that R&D resulted in *increasing number of patent filings* as shown above, the numbers of firms having *at least one patent granted each year abroad* and *in Taiwan* were 20 and 28 respectively. Many of them, however, have had *no patents granted yet* either *in Taiwan* or *abroad.* ***Trade Secrets*** were supposed to be more important than ***Patents*** for the firms in R&D Service, Industrial and Environmental Biotechnology sectors, and ***Plant Breeders' Rights*** for Agricultural Biotechnology sector, particularly. Therefore, most of them had *no patent application ever* either *in Taiwan* or *abroad* (Tables 5.23, 5.24 and 5.25).

Table 5.24: Results of Patent Filings in Taiwan for Respondents

Patent Filings in Taiwan	Number of Firms	Percentage of Total
Three Patents or More Granted Each Year	4	*2.5%*
One or Two Patents Granted Each Year	24	*14.7%*
Having Patents Granted but Not for Each Year	38	*23.3%*
None of Patent Granted Yet	30	*18.4%*
No Patent Application Ever	67	*41.1%*

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

Table 5.25: Results of Patent Filings Abroad for Respondents

Patent Filings Abroad	Number of Firms	Percentage of Total
Three Patents and More Granted Each Year	6	*3.7%*
One or Two Patents Granted Each Year	14	*8.7%*
Having Patents Granted but Not for Each Year	38	*23.6%*
None of Patent Granted Yet	33	*20.5%*
No Patent Application Ever	70	*43.5%*

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

For the utilization of patents or new technologies developed by the company, as many as 83 firms (55%) indicated that it was *applied to in-house production but not licensed out to other companies*, while at least 28 firms (19%) were able to *license their patents or technologies out to other companies*. However, 39 firms (26%) did *not* have the patents *applied to in-house production or licensed out to other companies* (Table 5.26).

Table 5.26: Utilization of Patents or New Technologies for Respondents

Utilization of Patents or New Technologies	Number of Firms	Percentage of Total
Both Applied to In-house Production and Licensed Out to Other Companies	25	*16.7%*
Licensed Out to Other Companies but Not Applied to In-house Production	3	*2.0%*
Applied to In-house Production but Not Licensed Out to Other Companies	83	*55.3%*
Neither Applied to In-house Production Nor Licensed Out to Other Companies	39	*26.0%*

Source: Based on the 165 survey responses (IDB project number 9200010069, 2003).

5.13. Conclusion

This dissertation tried to examine how national institutional context and firms' features at the aggregate level function together as a system to shape country-specific patterns in the development of biotechnology industry in Taiwan.

Based on the survey, most of Taiwan's biotech firms are still far too small, too immature, and they are specialized in very narrow niches (not product lines but few products; not platform technology but technologies for specific purposes). Furthermore, they have insufficient ability to access foreign innovative networks and to participate in international collaborative activities.

Compared with its strong IT industry, Taiwan's biotechnology industry is insignificant in the world at present and Taiwan's innovation system in the biotech arena appears to be fragmented. This fragmentation is due to the lack of a mechanism to integrate interdisciplinary efforts at the aggregate level, and even worse, due to inadequate institutional arrangements, the dichotomy of academic and industrial sectors. Therefore, Taiwan has had a difficulty in developing an industry of research-based firms and creating "academic entrepreneurs", which are crucial for biotechnology industry.