Scrutinizing a Policy Ambition to Make Business out of Science – Lessons from Taiwan

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ABSTRACT

Shih, T. (2009) *Scrutinizing a Policy Ambition to Make Business Out of Science – Lessons From Taiwan*. Doctoral Thesis No 143, Department of Business Studies, Uppsala University, 235pp.

The promotion of industrial development and economic growth is a vital issue for governments all over the world. The ideals guiding policymakers in their endeavours are that innovations based on new and advanced knowledge are central for industrial and economic development. In this context an issue, highlighted by local as well as national governments has been how to construct a system that can develop cutting-edge science and then transfer it to the business world for use.

Although identified generic features of successful regions such as Silicon Valley, have been copied there are few examples of how ambitions to "artificially" create policy supported high-tech based business regions and industries have succeeded. But one of the few successful examples of policy created high-tech industries often mentioned is the Taiwanese semiconductor industry. The envisioned development path of the Taiwanese semiconductor industry forms the foundation of contemporary Taiwanese industrial and innovation policy. This industrial development model applied on biotechnology in Taiwan, however, has been widely criticized for not fulfilling its promises.

This study aims to increase the understanding of this observation and sets out to investigate how developed solutions and resources become produced and embedded in business using structures. The dissertation is based on an empirical study of the industrialization of semiconductors and biotechnology in Taiwan, and is analyzed from a resource interaction perspective. By comparing the picture arising from this view with the Taiwanese policy interpretation it is argued that the Taiwanese industrial model is clearly over-simplified, omitting several important factors in the development of industries. The findings of this study are based on the notions that: resource combination occurs in different time and space; the new is always built on existing resource structures and; the users are important as active participants in development processes.

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ISSN 1103-8454

ACKNOWLEDGEMENTS

A few years ago I would not have thought about enrolling in a PhD program, less getting a PhD degree. However like this dissertation has tried to convey, life has many unexpected outcomes and different combinations of events take us on new paths. It has been an eventful journey which has been enjoyable and arduous at the same time. Not only has this endeavour been a training for me as a researcher, it has also enriched my life on other levels. I have travelled to the East and back to the West several times and gained many joyful insights of cultural, linguistic and social dimensions.

It is now time to thank everybody which has made this dissertation possible. First of all I would like to thank my academic advisers, Alexandra Waluszewski and Enrico Baraldi. They have both provided me with invaluable help from day one. Alexandra, which accepted me as a PhD student, although I knew nothing about industrial networks or biotechnology, has shown great patience and always believed in my project. I am lucky to have had an academic adviser that has been as enthusiastic and supportive as Alexandra. Enrico, my assisting adviser, has been equally encouraging and guided me through plenty of up-hills including helping me with the "stupid" questions which a PhD student might be too embarrassed to ask others.

A big thank you, as well, to all the people that have helped me throughout the research process with reading and commenting on my work. In the later stages these were especially Torkel Strömsten and Espen Gressetvold (who was a tough but constructive opponent at my final seminar). Others such as Håkan Håkansson, Lars Erik Gadde, Susanne Åberg, Magnus Persson, Josef Pallas, Åse Linné and Debbie Harrison to mention a few have also helped read various drafts and commented on my research during different stages.

In addition, this dissertation would not have been possible without the support and assistance of colleagues and friends all the way from the Nordic countries to Japan and Taiwan. Thank you to all the kind people that assisted me during my research and dissertation writing especially professors Robert Kneller and Katusya Tamai at the University of Tokyo, which helped me while being a researcher in Tokyo, and Elisabeth Hallmén and Merawi Tezera for valuable administrative and technical help. For my empirical data collection I would like to aim a big gratitude to GE Healthcare and George Yeh at Taiwan Liposome Company. I would also like to thank my friends and colleagues that have given me companionship and support throughout these years, particularly Malena, Sofia, Åse and Constance.

Lastly I would like to aim a special thought to my family, and my wife Yutzu, thank you for always being there to support me.

Uppsala, August 2009
Tommy Shih

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CHAPTER 1
INTRODUCTION

Making business out of science has become an increasingly hot topic in contemporary policymaking[1]. An issue highlighted by local as well as national governments has been how to construct a system that can develop cutting-edge science and then transfer it to the business world for use, in order to create economic growth. In many cases these transfer endeavours have however had disappointing results. This study aims to increase the understanding of this observation and sets out to investigate how developed solutions and resources become produced and embedded in using structures. The dissertation is based on an empirical study of the industrialization of two technologies in Taiwan, semiconductors and biotechnology, including Taiwanese policy's view of its role in the industrialization related to these technologies. Before the empirical study is presented let us first get an overview of the general context.

1.1 A policy ambition to create industries and new business resources based on innovation

The promotion of industrial development and economic growth is a vital issue for governments all over the world. The ideal that guides policymakers in their endeavours, strongly influenced by traditional economics and the innovation system approach, is that innovations based on new and advanced knowledge are central for industrial and economic development (OECD, 1996; Eklund, 2007). This observation is explained by the OECD through the following words (2007: p5):

[1] Making business out of science refers to the efforts to create new economic resources out of scientific research. In these endeavours policymakers have focused on promoting the scientific research (basic or applied) conducted at mainly universities but also at other research intensive organizations such as research institutes. It is these organizations that governments are promoting and expecting to better contribute to business development and economic growth (Eklund, 2007). The working definition of science in this study is thus the results related to both basic and applied research performed at universities and research institutes. This dissertation, however, focuses on investigating "developing, producing and using settings", regardless of where these settings can be found, whether in the academic world, research institutes or in corporate R&D laboratories.

> Today, innovation performance is a crucial determinant of competitiveness and national progress. Moreover, innovation is important to help address global challenges, such as climate change and sustainable development. But despite the importance of innovation, many OECD countries face difficulties in strengthening performance in this area. […] Governments can also play a more direct role in fostering innovation. Public investment in science and basic research can play an important role in developing ICT and other general-purpose technologies and, hence, in enabling further innovation. This highlights the importance of reforming the management and funding of public investment in science and research, as well as public support to innovative activity in the private sector. The latter calls for an appropriate mix of direct and indirect instruments such as tax credits, direct support and well-designed public-private partnerships, support for innovative clusters and rigorous evaluation of such public support.

To support development of advanced knowledge and to create a system that facilitates the transfer of the results from scientific research to industry has consequently been a main concern in contemporary policymaking. Although many countries can boast of prolific scientific production, it is also often voiced in policy circles that a knowledge paradox exists. The notion of a knowledge paradox or knowledge bottleneck refers to a view that an increased knowledge production in the academic sector has not led to a corresponding increase of its use in the business setting (Soete, 2002; Dosi et al., 2005; OECD, 2005; Audretsch & Keilbach, 2008).

However, empirical evidence suggests that commercializing scientific results is a cumbersome task with few traces of linearity. That it is not that easy to support artificially the development of new science-based solutions which will lead to knowledge-based industries and business regions has been experienced by many governments. An editorial in *The Economist* (2007: p4) gave the following opinion on this experience:

> EU officials, like government bureaucrats everywhere, are obsessed with creating geographic clusters like Silicon Valley. The French have poured billions into *pôles de compétitivité*; and Singapore, Dubai and others are doing much the same. There are dozens of aspiring clusters worldwide, nicknamed Silicon Fen, Silicon Fjord, Silicon Alley and Silicon Bog. Typically governments pick a promising part of their country, ideally one that has a big university nearby, and provide a pot of money that is meant to kick-start entrepreneurship under the guiding hand of benevolent bureaucrats. It has been an abysmal failure.

Despite these disappointing results there are examples of science-based business regions and industries that are presented as successful creations of policy. A salient example is the Taiwanese semiconductor industry based in Hsinchu. The emergence of this industry is intimately linked with Taiwan's economic success. In just a few decades, the Taiwanese economy transformed itself from being dependent on agriculture to become one of Asia's high-tech centers. In short the story commonly told is that in the early 1970s Taiwan was a backwater economy. The country was dependent on agricultural production and labour-intensive manufacturing of textiles, electronic components and plastics. Given this situation, Taiwanese policymakers decided that it was time to direct industrial production towards more knowledge-intensive sectors. What preceded this ambition was an already expanding economy. Import-substitution policies for self-sustainability in a number of critical industries had been implemented in the 1950s with success.

In the 1960s export-expansion policies were put in action to attract foreign capital. Through low labour costs and generous investment rules Taiwan could draw foreign investment in the manufacturing of labour-intensive products. By the late 1960s the export promotion policy had turned the chronic trade deficit into a consistent trade surplus. Agriculture was still an important economic sector but revenue coming from non-agricultural manufacturing industries, such as consumer electronics, toys, petrochemicals, plastics and textiles, was driving the economic growth. Policymakers were determined that it was time for Taiwan to take the direct leap into more advanced industrial sectors and move up a step on the economic development ladder. A field that was identified by the government as a future industry and which would allow Taiwan to take this development leap was semiconductors.

Public policies were implemented to speed up development in a hitherto non-existent semiconductor industry. The focus on semiconductors turned out to be beneficial for the Taiwanese economy. Since the 1980s the economic growth of Taiwan has been closely associated with the development of the semiconductor industry located in Hsinchu, also known as the Silicon Valley of Taiwan. Two decades after the emergence of the first few semiconductor businesses in the early 1980s, the Taiwanese semiconductor industry was ranked the fourth largest in the world[2] and consisted of nearly 400 companies[3]. At the end of 2005 the Taiwan Semiconductor Industry Association (TSIA) estimated that 60 percent of worldwide semiconductor foundry, package and testing revenue, 25 per cent of worldwide

[2] Defined in terms of production value, surpassed only by the USA, Japan and Korea.
[3] The companies can be classified as: 268 IC design houses, 6 wafer suppliers, 4 mask makers, 13 fabrication companies (fabs), 33 packaging houses, 35 testing houses, 15 substrate suppliers and 19 chemical suppliers (TSIA, 2006).

semiconductor design revenue and 25 per cent of worldwide DRAM revenue were generated by Taiwanese companies. The total economic value generated by the Taiwanese semiconductor industry totalled 1118 billion New Taiwan Dollars (roughly 33 billion USD) at the end of 2005 (TSIA, 2007).

Regardless from what vantage point the emergence of the semiconductor industry and the Hsinchu region is viewed, it appears impressive. Within a few decades, a new industry resting on high-tech and innovation has emerged in a country which had previously relied on traditional industries and small and medium-sized companies with weak R&D capacity. The most common interpretation of the Taiwanese semiconductor development is that it was a result of public policy engagement in coordinating industrial development (see, e.g., Liu, 1993; Mathews & Cho, 2000). This view, also stressed by Taiwanese government policy, is exemplified by the quote below by the Director of the Biotechnology Program at the *Science and Technology Advisory Group* (STAG), a Taiwanese policy organization:

> The semiconductor industry was a creation of government policies. It was our government that identified semiconductor technology as Taiwan's chance to catch up with developed countries. There was no semiconductor industry when ITRI started its operations in the 1970s and basically everything was developed from nothing (Interview, Lee Chong Chou).

Subsequently, the policy interpretation of how the semiconductor industry emerged has come to serve as a role-model for how to create new industries in Taiwan. The main policy measures undertaken were aimed at the establishment of public research institutes, a public provision of R&D, and the subsequent diffusion of the research results to the private sector (Liu, 1993; Chang, Shih & Hsu, 1994). Under the guidance of this template the Taiwanese government introduced its promotion plan to develop a biotechnology industry in 1995. The quote below from the Ministry of Economic Affairs (MOEA, 2003b: p1) expresses this development ambition:

> The government has put a lot of effort into promoting Taiwan biotechnology, including the sector as an important part of the Challenge 2008: The Six-Year National Development Plan, as well as including the industry in the Two Trillion, Twin Stars project. In the coming decade, the biotechnology industry may very well be the major driving force behind Taiwan's economic development. We believe that with government policies driving the development of the industry, as well as the all-out promotion efforts

> under the direction of the Ministry of Economic Affairs, the biotechnology industry will retrace the steps of its illustrious predecessors – the semiconductor industry and the information products industry. We look forward to the day when Taiwan will be able to boast a booming biotechnology industry. This will not only fire up the engines of national progress, but will also expatriate Taiwan's entry into the global biotech business network, ensuring continued economic prosperity.

Since the first promotion plan for biotechnology, the Taiwanese government has devoted a considerable amount of resources to creating a biotechnology industry. The ambition to concentrate on developing science-based industries in order to maintain economic competitiveness was further emphasized in 2000, when President Chen Shui-Bian[4] proposed to transform Taiwan into a "Green Silicon Island". This provided additional fuel to the enlargement of the biotechnology sector and major efforts to reform vital areas in the planning and promotion of science which was considered suitable for biotechnology business. In addition efforts to create a system for the transfer of scientific research results to the industry intensified. For example, in the academic sector, government grants were earmarked for projects assumed to have "commercial" value and researchers were given incentives to patent their discoveries. To support the biotechnology industry, science parks were established all over the island. In order to facilitate the commercialization process of scientific advances, research institutes were commissioned to serve as the bridge between academia and industry. In addition a number of incubation centers were also created within research universities and institutes (MOEA, 2002, 2005, 2008b).

As a result of the extensive support program, company creation became fashionable, with start-ups springing up from universities as well as the private sector. Furthermore a number of established companies diversified into biotechnology or changed their line of business partly due to the generous government incentives. With a generous definition of what is considered biotechnology, the number of biotechnology-related companies had grown to a total of 296 in 2003. Looking at the pure numbers this is an impressive achievement considering there were only two biotechnology companies established in Taiwan prior to 1995, according to the Taiwanese government. In fact, the majority of these 296

[4] President Chen Shui Bian (Democratic Progressive Party) declared in his presidential inauguration speech that Taiwan should concentrate on knowledge-based sectors in order to maintain economic competitiveness and sustainable development. The goal is to transform Taiwan into a "Green Silicon Island" (Chen Shui Bian, Internet).

biotechnology companies were not actually newly founded [5] but were rather existing enterprises redefined as operating in the biotechnology industry. They were involved in various fields, including drug development, genomics, cosmetics and health foods (MOEA, 2004)[6]. In spite of the impressive growth of biotechnology, as demonstrated by government statistics, the industry has had difficulties living up to the high expectations set by state planners and investors. Hsu et al. (2005: p281) provide the following comment on the Taiwanese biotechnology industry:

> Although the Taiwanese Government has put in a great deal of effort, the progress of biotechnology industry has not been as good as predicted. The total industrial output of Taiwan's biotechnology industry was less than 600 million US dollars in 2000, and most of the output was traditional bio-product related, rather than modern biotechnology products.

The picture of failing biotechnology industries or high-tech regions is, on the other hand, not anything unique, as stated above. All over the world, policymakers and investors have had to revise their expectations on at least the short-term potential of science-based industries (Waluszewski, 2004b). Despite the rising number of "failures" innovation, especially based on frontier science, is commonly accepted as a means of wealth creation and a solution to a number of global challenges. This view is heavily promoted by the OECD (2007: p3):

> Undoubtedly the capability to innovate and to bring innovation successfully to market will be a crucial determinant of the global competitiveness of nations over the coming decade. There is growing awareness among policymakers that innovative activity is the main driver of economic progress and well-being as well as a potential factor in meeting global challenges in domains such as the environment and health.

Hence endeavours of contemporary policy to promote scientific research for the development of value-generating innovations and new business resources have not seemed to slow down. In general, these attempts are based on three main components: First, to increase the development of science as a source of innovation; Second, to turn the science-based discoveries and inventions into innovative solutions in a producing business setting and; Third,

[5] Up to 2002, just 100 new biotechnology companies had been established in Taiwan (Hsu et al., 2005), suggesting that the majority of the companies in the biotechnology industry were actually already established companies.

[6] The majority of the companies were involved in areas mainly considered as "low tech" biotechnology, i.e., the development of products without the use of advanced production technologies or methods (Interview, Julie Sun).

to establish a system that can diffuse these innovations and lead to, what is believed, a widespread use in the business setting. Simply said, the policy recipe often encountered is to develop new science-based solutions and establish a structure that can translate these to commercial solutions, which can be launched on the market. This process is in this dissertation referred to as an *innovation coming into being*, i.e. an innovation encompasses both invention as well as a widespread use.

However, empirical evidence also shows that the development of science-based industries has not been as straightforward as the recipe foretells. The challenge which has mainly been acknowledged is the lack of economic use of what is developed. For example, in a study on innovation in the European Union, Kogan (2000: p174) concluded:

> The research policy paradigm was already well embedded in a competitiveness/innovation oriented understanding and an understanding of the so-called European paradox, that is, the conjecture that EU member states play a leading global role in terms of top-level scientific output, but lag behind in the ability of converting this strength into wealth-generating innovations.

Although the lack of use is considered a challenge, it is the problems related to transfer and diffusion that are unilaterally stressed in contemporary policy analysis. Arguably, use should be an issue of greater concern, which at present seems to be lacking from the debate. Since the economic use of new solutions has been a neglected issue in policymaking let us go deeper into this issue and also identify the problem area of this dissertation.

1.2 Identifying the problem

What has been at focus hitherto is a policy agenda which targets the development of new advanced knowledge as the main source of economic growth. This agenda takes the characteristics of a technology-push model, where policymakers have tried to identify the scientific areas deemed important for industrialization and creation of innovations. Furthermore, through establishing a proper transfer system of innovations, use can be enabled, which leads to economic growth. Problems commonly associated with this development model are that knowledge production is lacking, the transfer system is incomplete, or that the

industry does not have enough absorptive capacity[7] (Håkansson & Waluszewski, 2007). However, an issue, which seems to have been neglected by policymakers is whether what is considered as a breakthrough technology or discovery in an academic or research setting also can contribute to positive economic effects in a user structure, i.e., among paying customers. This problem is pointed out by Pavitt (2000: p456):

> Whilst considerable resources have been devoted by governments to trying to identify and agree on fields of potential usefulness, relatively few have been devoted to identifying what users of academic research (particularly business user) expect from it.

Others also stress the importance of investigating the problem of creating use of new knowledge in a business structure:

> The policy efforts to connect scientific knowledge with business development can be characterized by their strong focus on the supply and intermediary side […] However, a question that is less often considered, if even reflected upon at all, is how the user structure, i.e. new and established businesses and organizations, can embed this knowledge into a business world full of already activated and interdependent solutions (Håkansson & Waluszewski, 2007: p10).

Hence what is of interest is not only what can be developed and produced but also, equally important, is if this fits into the existing structures of the users. As Akrich, Callon and Latour note, innovations, no matter how groundbreaking they are, do not automatically find a use. Instead the authors contend that:

> The adoption of an innovation, whether that of Porvair, the continuous flow method or the installation of a robot, goes through a series of decisions which depend on the particular context within which the innovation is to be inserted. The evaluation of the disadvantages and advantages of an innovation is entirely in the hands of the users: it depends on their expectations, their interests, on the problems which they raise (Akrich, Callon & Latour 2002: p202).

[7] These are also explanations commonly provided by studies based on the innovation system or triple helix approaches.

With the above understanding, how new science-based solutions can accompany already existing business structures is an important part of a puzzle of how innovations come into being and generate economic value. This issue will now be discussed in closer detail.

By "structures" I refer to combinations of existing material as well as immaterial resources in the empirical landscape. Each one of the resource structures which are associated with activities related to development, production and use has its own rationale. For instance, in the academic world where most scientific discoveries are made, the guiding principle for the activity is novelty and uniqueness (Chalmers, 1999). The primary goal in this setting is often novelty in itself of the developed solutions and not foremost the economic returns they can potentially bring in. A developing structure, involving developers of science-based applications, where a large proportion of funding comes from the business world, might be more bound by economic pressures but still relate its activities to research. Hence, when developed solutions are confronted with producing and using structures in the business setting there are often clashes in rationales. The goals driving the producing and using structures are, in comparison with a developing structure, more concerned with how new solutions can fit into and create value for investments already made (Håkansson & Waluszewski, 2007).

Consequently, if a company wants to use a cutting-edge technology developed at a university, it cannot look at novelty per se as the deciding factor. Instead what is more important is how the technology can create value for the company's already existing investments. Even more important is how the company's environment can benefit from it and gain value. For example, how does the technology fit with the existing structure of investments (such as machines, personnel or business relationships) made by the company's suppliers or customers? An investment in a new technology always has consequences not only for the individual company but a whole structure of related resources used by also other companies and organizations. Thus the less the new technology can be used with these structures of existing investments and create value, i.e., the more new investments and time is required, the less embedded it will be. In this aspect, embedment of new resources is a consequence of what positive economic effects the new has on the existing structures (Håkansson & Waluszewski, 2007; Håkansson et al., 2009).

The importance of considering anything new in relation to existing structures has been underlined by a number of scholars engaged in empirical studies of technological development, including Rosenberg (1976, 1982) and Hughes (1983, 1987) among others. These authors introduce the concept of producer-user interaction as the basis of technological development. A central proposition in the notion of producer-user interaction is that users as

well as producers are active in the development of various solutions. That is to say that users are not only passive receivers, but also that they interact closely with producers in development activities. The concept of producer-user interaction has been applied within various theoretical fields. In the innovation-related literature, scholars such as von Hippel (1988) have specifically investigated the importance of users as the leading contributors in the innovation process. The matter of interaction between production of knowledge and economic demand is also in focus among scholars in Science and Technology Studies (STS). An issue of increasing interest is how science and innovations are actually used when embedded into the business setting (see Hughes, 1983, 1987; Gibbons et al., 1994; Bijker & Pinch, 1997; Nowotny et al, 2001, Grandin et al., 2004; Shapin, 2004).

The creation and development of producer-user interfaces has been a key issue within the Industrial Marketing and Purchasing (IMP) network approach[8], which in this dissertation is referred to as an *interactive perspective*. What is suggested by the interactive perspective is that it is within established producer-user interfaces that many innovations have their source (Håkansson, 1989). In this context several scholars have investigated how technological development occurs in industrial networks, for example, Laage-Hellman (1989), Lundgren (1991), Håkansson et al. (1993), and Håkansson and Waluszewski (2002), to mention just a few. Others, such as Andersson (1996), have studied the complex change process of turning science-based applications into business applications[9].

More recently, Håkansson, Waluszewski and colleagues (Håkansson & Waluszewski, 2007; Harrison & Waluszewski, 2008; and Waluszewski et al. 2009) have investigated how knowledge and science-based solutions are embedded into a business setting. What is suggested by these authors is that to investigate the introduction of a science-based innovation we need to take into consideration what types of interfaces the new solution has to fit into, in its developing and producing-using settings respectively. To survive in an established producer-user interface, it is not what novel qualities a new solution has per se which is the deciding factor, but rather what effects it has on direct and indirect related interfaces on producer and user sides. This "requirement" does not always fully correspond to what is desirable of a new solution born inside academia, research institutes or other highly research-intensive environments. Thus to understand how solutions that are considered to have great

[8] See www.impgroup.org for more information on the IMP network approach.
[9] In his doctoral dissertation Andersson (1996) followed the emergence and development of the industrial network of Pharmacia Biotech between the years 1959-1995. Pharmacia was a major pharmaceutical company founded in Stockholm, Sweden in 1911 and moved to Uppsala in 1951. In 1986 the company was renamed Pharmacia Biotech. Through a number of mergers and acquisitions Pharmacia the owner structure changed several times in the 1990s and forward. In 2004 the company was acquired by GE Healthcare.

potential within a developing setting are successful or fail in producing-using settings, we need to investigate these effects on direct and indirect related interfaces in the existing business structures. With this understanding the picture changes from, for example, the commonly used notions of push or pull[10].

1.3 Research aims and questions

This study originates in an observation that policymakers all over the world have, in the last decade, placed increased emphasis on stimulating the development and production of science in order to promote economic growth. A basic idea that has been popular in policy circles is that science is a significant source of innovation, which in its turn is a major source of new business resources. With such a development scenario in mind, it becomes important to promote science that is thought to lead to innovations and to create a system that supports the transfer of innovative solutions from research to the business world. However, a commonly acknowledged problem is that the increased development of science has not been used in the business world at a corresponding rate. The empirical question can thus be formulated as:

Why do new science-based solutions have difficulty becoming innovations?

In this dissertation I will not focus on the transfer mechanism, that is to say, how to design a system in which science can become produced and thereafter directly transferred to the industry. This area of research has already received much attention in the innovation related literature as well as in policy analysis. Instead, to increase the understanding of the empirical problem, I will consider developing, producing and using settings, and investigate the interaction between them (regardless of how far or close the empirical settings are from each

[10] For instance, as described by Lundvall (1988: p28): "Innovational activities are often treated as a linear process starting within basic research and ending in economic growth. The results from basic research are regarded as inputs to applied research. Inventions taking place within science are supposed to give rise to innovations. As innovations become diffused they affect productivity and growth in the sphere of production. This unidirectional flow of information might be hampered by lacking competence on behalf of potential users and considerable time lags might be involved – but it is still regarded as unidirectional. Such a perspective will correspond to a technology policy supporting science and R&D-activities. Another approach has emphasized the importance of demand as a factor stimulating and directing innovations. When demand grows, it will pull R&D inventions and innovations forward, and result in productivity growth. Such a perspective might give rise to policy recommendations of a laissez-faire character. Innovative activities are assumed to adjust automatically to the market forces. A user-producer perspective raises critical objections to both of those two schools. The supply school under-estimates the active role of users in the innovation process. The demand school does not distinguish demand, as a quantitative category, from user needs as a qualitative category."

other). More specifically I will investigate how resources from developing settings become produced and embedded in using settings, an area to which policy and also earlier research seem to not have paid much attention. With this background, the research scope of this investigation is twofold and the aims are formulated as follows:

1 *To increase the understanding of the processes whereby new material and immaterial resources are developed, produced and used.*
2 *To discuss the role of policy in these processes.*

These two research aims are examined through an empirical study with three different layers:

1. *A study of the emergence of the Taiwanese semiconductor industry.*
2. *A study of the interpretation of the emergence of the semiconductor industry as a successful creation of government policy, and how this interpretation has guided the policy creation of a biotechnology industry.*
3. *A study of an emerging biotechnology industry, including two detailed studies of biotechnology business development.*

These layers provide a foundation for the following research questions:

1. *How does the relation between science-based solutions and business development appear from a policy perspective?*
2. *How does the relation between science-based solutions and business development appear from an interactive perspective?*
3. *How do the two respective pictures compare?*

1.4 Structure of this dissertation

The dissertation is structured as follows. In chapter 2 the theoretical frame of reference which is based on the IMP network approach is presented. Chapter 3 discusses the methodological approach. Chapters 4 to 7 make up the empirical study which will give an increased understanding of the identified research issues. The empirical study which is unfolded over four different parts starts in chapter 4 with an account of the emergence of the Taiwanese semiconductor industry and how this emergence has been interpreted and translated into a specific model on how to create new industries. This is followed by chapter 5, which offers a description on how the model is applied by the Taiwanese government to create a biotechnology industry, which so far has been a disappointment from an economic perspective. To learn more about the development ambitions of the Taiwanese biotechnology industry, two specific development projects are provided as examples. Chapter 6 depicts a policy-driven vaccine project as a part of the government's ambition to create a domestic vaccine industry. Chapter 7 gives an account of the development of liposome-based biopharmaceutical drugs in Taiwan. Both examples from chapters 6 and 7 have been supported by policy, but through different ways and with very different outcomes. In Chapter 8 the analysis is presented which is followed by a concluding discussion in Chapter 9.

CHAPTER 2
THEORETICAL FRAMEWORK

In this chapter the theoretical framework, which is mainly based on the IMP network approach is presented. The framework will be used in two ways. First, it gives an empirical based understanding of the business landscape and provides important insights into the intricacies of embedding science-based solutions in a business setting; i.e. how science-based innovations come into being. Second, the IMP approach provides research tools to analyze the resource interaction that occurs in developing, producing and using settings. The analytical framework which is later discussed is applied to investigate how resources are developed, produced and used. This chapter is divided into two sections. In the first section an empirical picture of the business landscape is presented. The second section discusses the three empirical settings as well as the research tool, the 4R model. The analytical framework is summarized at the end of this chapter.

2.1 Basic characteristics of the business landscape

A common characteristic of all kind of business life, encountered in over four decades of IMP research on business exchange, is interdependence. Companies interact in order to create value, in this process relationships are established and dependencies are created. These observations are also the cornerstones of the understanding of the business landscape promoted by the IMP approach. The approach has its roots in research carried out in the late 1960s[11]. The research field started as a reaction against the stylized assumptions of markets provided by neoclassical economics[12]. From empirically driven studies it was noticed that the behaviour of buyers and sellers in industrial markets did not correspond well with the

[11] This section is not intended to be a comprehensive overview of the emergence of the IMP network approach, but an outline of the main assumptions. For a more detailed description of the emergence of the IMP network approach see Håkansson (1982), Håkansson & Ford (2006) or Mattsson & Johanson (2006).

[12] The general assumptions of neoclassical economics focus on the determination of price and input in the markets through the supply and demand function. The choices that are made by individuals and firms are made in accordance with rational behaviour (given available information and production factors). Furthermore the firms and individuals act under the constraints of maximization of profit and utility. The interaction between buyers and sellers consists of single discrete exchange episodes. In the traditional market view, buyers are also considered as passive. There are many buyers and sellers on the market which can enter and exit with ease, i.e., an atomistic structure (Håkansson, 1982; Lundvall, 1988).

assumptions provided by mainstream economic theory (Håkansson, 1982; Håkansson & Snehota, 1995; Håkansson & Waluszewski, 2002; Ford et al., 2003).

The empirical view which IMP researchers brought forward concerning the behaviour of actors in industrial markets was distinctly different from that based on neoclassical economics. For instance, an early observation was made in Johanson's (1966) dissertation, where the author stated that the business activities of companies were often embedded in relationships. What was suggested was that companies do not seek profit maximization at every single exchange but rather engage in problem-solving processes through long-lasting relationships with customers. This observation could not be explained by the prevailing theories at the time. Hence, Johanson's study identified a major contradiction to the mainstream market theory and inspired a number of other studies which attempted to explain an empirical reality of the business landscape based on interaction.

The term "Industrial Marketing and Purchasing" was established in 1976 when the so-called IMP Group was formed. It consisted of researchers from five different countries and some early studies published were those of Håkansson and Snehota (1976); Håkansson, Johanson and Wootz (1977) and; Ford (1978, 1980) to mention a few. Collectively these studies proposed that the behaviour of companies was characterized by interdependence and, to handle this interdependence, interactions and long-term relationships had an important role. The first large project of the IMP Group resulted in a book edited by Håkansson, *International Marketing and Purchasing of Industrial Goods – An Interaction Approach* (Håkansson, 1982). Håkansson and the IMP Group had four main objections against the traditional ways of explaining behaviour on industrial markets which were formulated as follows (Håkansson, 1982: p9):

> Firstly, we challenge the concentration of the industrial buyer behaviour literature on a narrow analysis of a single discrete purchase. Instead we emphasize the importance of the relationship which exists between buyers and sellers in industrial markets. This relationship is often close. It may also be long term and involve a complex pattern of interaction between the two companies. Secondly, we challenge the view of industrial marketing as the manipulation of the marketing mix variables in order to achieve a response from a generalized, and by implication passive market. We believe it necessary to examine the interaction between individual buying and selling firms where either firm may be taking the more active part in the transaction. Thirdly, we challenge the view which implies an atomistic structure in industrial markets. This view assumes a large number of buyers and sellers, with ease and speed of change between different suppliers

> for each buyer and ease of market entry or exit for those suppliers. Instead, we stress the stability of industrial market structures, where those present as buyers or sellers know each other well and are aware of any movements in either the buying or selling market. Fourthly, we challenge the separation which has occurred in analysing either the process of industrial purchasing or of industrial marketing. In contrast, we emphasize the similarity of the tasks of buyers and sellers in industrial markets. Both parties may be involved in a search to find a suitable buyer or seller, to prepare specifications of requirements or offerings and to manipulate or attempt to control the transaction process. This means that an understanding of industrial markets can only be achieved by the simultaneous analysis of both the buying and selling sides of relationships.

The empirical experiences described above are what make up the core assumptions of the IMP network approach and has resulted in three main research tools: the interaction model; the ARA model and; the 4R model (Håkansson et al., 2009)[13]. Since the emergence of this research field, a large number of empirical studies have been conducted with the IMP perspective, covering areas such as purchasing, marketing, technology and business development. However, this chapter is not aimed at providing a comprehensive overview and history of the IMP network approach (for an overview of some earlier work of IMP, see Ford 1997; Håkansson & Waluszewski, 2002; Mattsson & Johanson, 2006). Instead the aim of this section is to show what processes characterize the business landscape in general, and particularly the development of producer-user interfaces. Below, I will continue to discuss the business landscape where innovations are developed, produced and used.

[13] The first research tool developed in the IMP network approach was the *Interaction Approach* (see Håkansson, 1982) focusing on the relationship between two business partners, i.e., at the level of the dyad. The interaction was characterized by single exchange episodes but also of extended and thicker interaction. As a result of interaction it was observed that business relationships were developed with a consequent adaptation between the two parties (Håkansson, 1982). These relationships, ranging from distant to close, were often stable but included both cooperation and conflict (Håkansson & Waluszewski, 2002). The understanding that the dyadic relationship was also embedded in a larger structure of relationships, a network, later gave rise to the *ARA model,* an abbreviation of actors, resources and activities. Actors were defined as groups of individuals, parts of organizations, organizations, or groups of organizations which develop and maintain relationships with each other. Actors performed activities and controlled resources. Resources were connected to the actors as well as to the activities. They were means used by actors when they performed activities. Furthermore resources were used in activities that were needed in order to change other resources. Activities were undertaken when actors used certain resources to change other resources in various ways. The activities thus bonded resources to each other and gave them value (Håkansson & Snehota, 1995). According to these assumptions, the three different dimensions (*actor*, *resource* and *activities*) of the ARA model provided an extended network picture. Without any dimension having priority over the other they mutually affected each other and had different boundaries and logics creating different but interrelated images of an industrial network (Ford, 1997). Following the ARA model, Håkansson and Waluszweski (2002) paid more attention to the investigation of the interaction between resources in the 4R model (the model will be explained more closely later in this chapter).

Interaction – a key process in the business landscape

A cornerstone in the IMP approach is the study of *interaction*. As it is described by Håkansson and Snehota (1989) no companies act in isolation, instead they interact with suppliers, customers, competitors, authorities and non-governmental organizations in order to create value. Thus interaction is a key process in the business landscape which shapes the features of companies, their activities and resources. It can be in the form of uncomplicated exchanges of a product for money, and at other times it can be when two units collaborate deeply over a long period of time to develop a new technological solution. Irrespective of the nature, interaction between various actors creates effects with both positive and negative consequences. Furthermore there are always anticipated and unanticipated effects from interaction, as neither the motives of people nor the content of the resource combinations and activity links they represent can be fully known in advance (Håkansson & Waluszewski, 2002; Ford et al., 2003).

In this dissertation it is the interaction between resources which is of interest. An important observation of the business landscape is that demand and the features of resources are not given in advance but are created by different actors from developing, producing and using structures in interaction processes (Laage-Hellman, 1989; Lundgren, 1991; Wedin, 2001; Håkansson & Waluszewski, 2002; Håkansson & Waluszewski, 2007; Håkansson et al., 2009). Furthermore interaction between different actors also results in the development of relationships between actors, which become a medium to influence others and to handle the way activities are performed or how resources are used in a larger structure of actors (Ford et al., 2003). Through extended interaction, interdependencies between organizations, people and material things are created (Ford et al., 2003). In the next section this will be discussed in more detail.

A business landscape characterized by interdependencies and relationships

The notions of interdependency and relationships hold a central position in the understanding of how the business landscape is structured. The understanding proposed by the IMP framework can be summarized as follows:

> The IMP approach builds on the interaction that takes place between active customers and active suppliers in relationships. The companies in these relationships are interdependent for sales, supplies, information development and for access to other companies elsewhere in the surrounding network (Ford et al., 2003: p6).

As relationships are systematically developed, Håkansson et al. (2009: p2) conclude that "they do not only connect dyads, but they do also connect indirect related companies in network-like structures". A result of the formation of relationships over time is that companies and organizations become increasingly dependent on each other, on their customers, suppliers and other counterparts. Thus actors, material and immaterial resources, and activities are systematically related to each other.

From the IMP perspective interdependence specifically relates to the connectivity between actors, resources and activities, implying that what happens in one business transaction can have consequences not only for the parties directly involved in the transaction but also indirectly for other related business actors. In other words, a change in one part of a resource structure also has effects on the rest of the structure. For example, from a business perspective, if a new production facility is brought into a company, it needs to be related to a large number of resource interfaces both within and across company borders, including human as well as material resources (Hughes, 1987; Wedin, 2001; Håkansson & Waluszewski, 2007). Why, then, do companies voluntarily limit their opportunities to change counterparts swiftly and to act more independently? According to Håkansson et al. (2009: p2), the main reason is that:

> These connected relationships - which on the surface can appear as social constructions - are based on economic interests and seem to be a way to affect two important company issues: efficiency and innovativeness.

Thus relationships are based on an economic rationale and offer counterparts the possibility to influence others. Through relating to each other in a long-term perspective, material and immaterial resources are adjusted to each other, activities are linked, exchanges become more standardized and counterparts learn from each other. In these ways efficiency and innovativeness can increase (Håkansson & Snehota, 1995; Gadde & Håkansson, 2001; Ford et al., 2003). But the question remains of why business relationships should be the most important sources of innovation and technological development?

Business relationships – an important source of innovations in the business landscape

What has been outlined is a business landscape where companies interact with other companies and organizations in order to create value. This process is characterized by the formation of business relationships which emerge through extended interaction over time. The relationships create and direct interdependencies between people and other immaterial and material things across company and organizational borders. Furthermore, through these relationships, exchanges and processes become standardized; activities and resources are organized in network-like structures leading to higher efficiency. Thus, any company's internal organizing of material and immaterial resources is related to the organizing that takes place within and between other companies (Håkansson & Snehota, 1995; Håkansson & Waluszewski, 2002; Ford et al., 2003).

So far only the positive aspects of relationships and networks have been discussed. However it should also be acknowledged that relationships do not only relate to positive contributions such as higher efficiency and innovativeness. There is another side of relationships that is characterized by conflicts. Whenever two counterparts interact there is conflict to a greater or lesser extent, for instance in the form of tough negotiations, clashes in goals and so forth. These processes do not necessarily mean that the outcome will be negative; friction can also be a source of advancement. On another note, established relationships can make it more difficult for other solutions (outside of the relationships) to contribute to innovativeness and efficiency (Gadde & Håkansson, 2001; Håkansson & Waluszewski, 2002). Hence business relationships can be said to be characterized by both positive and negative effects. On the one hand, they decrease independence for companies and related counterparts, but on the other hand they increase efficiency. The important point here though, does not really relate to whether they are good or not but just that they are an integral part of the business landscape. Or as it is stated by Ford et al. (2003: p37):

> It is not a matter of choice for a company whether or not it should have relationships. All companies have relationships now and all companies have always had them. We would go as far as to claim that a company cannot exist without relationships. But those relationships can vary in content, strength and duration.

In this context empirical evidence reflects that it is within the established relationships between producers and users where innovations are mostly created. For example, in a study in the IMP setting (see Håkansson, 1989, in Håkansson & Waluszewski, 2007) where 123 Swedish companies were investigated, it was indicated that the most important sources of new knowledge and innovation came from existing customer and supplier relationships, while only a minor part of the companies' most important development relationships were with external R&D units. Furthermore it was shown that only a few customers and suppliers were involved in the major exchange processes. Hence innovation occurred mostly within relationships between a limited number of customers and suppliers.

Given these empirical experiences an interesting issue is, then, how solutions that have been developed in settings other than the existing producer-user interfaces are introduced in the latter. As was mentioned above, established relationships can make it difficult to introduce solutions from outside the existing producer-user interface. Let us continue with outlining some empirical experiences on the introduction of science-based solutions (developed outside of established business structures) in the business landscape.

Science-based innovation in the business landscape – characterized by non-linearity

One of the most influential concepts in the twentieth century designed to aid policymakers in modelling innovation and technological development has been the linear model[14]. The term, popularized by Vannevar Bush (1945), refers to a unidirectional chain of progression of how scientific efforts become value-generating innovations in the industry. The process is characterized by each part of the value chain, from basic research to applied research and lastly to the industry, being independent of each other. That is to say, the different sectors do not interact and businesses are perceived as passive users of scientific results (Lundvall 1988; Cohen et al., 2002; Grandin et al., 2004).

The linear model has however been heavily criticized by both practitioners and academic commentators on empirical grounds. For instance, scholars such as Gibbons and

[14] The view that innovation or technological change come from scientific discoveries has been well established in policy circles. For example, Freeman (1995: p9) comments: "A linear model of science and technology 'push' was often dominant in the new science councils that advised governments. It seemed so obvious that the Atom Bomb was the outcome of a chain reaction: basic physics => large-scale development in big labs => applications and innovations (whether military or civil)."

Johnston (1975), Kline and Rosenberg (1986), Nelson (1990), Rosenberg (1994) and van de Ven et al. (1999) have all provided non-linear interactive accounts of innovation and technological development. In their empirical descriptions, scientific research is sometimes a direct source of innovations but they also demonstrate that science often does not have a direct or visible role. These observations do not imply though, that science is unimportant in the development of innovations or technological solutions – but rather that is mostly indirect suggesting that production and use are not independent of each other. This is explained by Basalla (1988: p92) through the followings words:

> Scientific knowledge that spurs technological innovation need not be the latest nor need it appear in its purest form; second- or third-hand conceptions of scientific advances can and do serve technology well.

Similarly Håkansson and Waluszewski (2007) contend that science is inherently present in most innovations although the direct contribution might be difficult to distinguish clearly. For example, how do we separate what part of a mobile phone or a computer is made from scientific knowledge and what is not? In a practical sense the difficulty in clearly identifying the contribution of science, nonetheless, does not mean that there is no benefit from it. The way scientific knowledge is used to develop or improve technologies is just mostly indirect and partial (Pavitt, 2004). But not only is non-linearity in time often a part of the findings when investigating the production and use of innovations, another dimension also relates to space. For example, Tidd et al. (2005) demonstrate that different solutions which have been developed independently of each other in different contexts are regularly combined, sometimes through accidental events, to create new innovations. In this respect the development of innovations becomes a myriad of "expected outcomes as well as unexpected effects, where new and old solutions are tried and retried" (Wedin & Waluszewski, 2003: p4). Or, as stated by Van de Ven et al. (1999: p4), the processes are "neither stable and predictable nor stochastic and random".

What are then the important lessons from these experiences? One obvious lesson is that it is not where the solution originates from which is of main interest, whether it might be science or technology. Furthermore what is suggested is the significance of maintaining a "multi-process view" when investigating developments, as advocated by Håkansson and Waluszewski (2007: p16). Thus, to catch developments where solutions are developed,

produced and used in a non-linear fashion, we could also start from the other direction, i.e., how new or old solutions are used in existing business structures.

As described, for example, by von Hippel (1978, 1988); Van de Ven et al. (1999); Håkansson and Waluszewski (2007) new solutions will always be used in a business landscape where existing resource structures are already in place. These structures, which cannot be fully known in advance, will inevitably influence the use and embedding processes of anything new. What is of interest is how new solutions can fit into and create value for an already existing structure of material and immaterial resources, where each resource is specifically related to other resources through systematic organizing (Gadde & Håkansson, 2001; Håkansson & Waluszewski, 2007; Håkansson et al., 2009). Since these processes can only be studied in retrospect, it is impossible to study empirically how new solutions developed in a research setting will be applied in a user setting before they have been embedded.

Embedding new solutions and innovation – Stability and change in existing structures

When considering the embedding of new solutions or resources, an important issue concerning use is how they can be embedded into an already *existing structure* (Baraldi & Strömsten, 2005). According to Håkansson and Waluszewski (2007: pp17-19), this is a continuous organizing process where there are two important features:

> First, the existing structure is the result of a systematic combining where individual resources are built together into intricate constellations. However since most resources are used in different, sometimes contradicting combining processes, they are always exposed to tensions; to endeavours to combine them in new ways. Second since the existing structure is the starting point for further combining, this will strongly influence the emerging changes. Thus, the use of resources in an organised world means that the replacement of one resource for another will always create reactions – not only at one but at several related resource interfaces.

As Wedin (2001) states, when resources are used in different or overlapping networks, causing a wide range of conflicting logic, embeddedness will limit the possibility to take advantage of them. In this context, several academics suggest that the introduction of a

resource, such as a new technology, depends on how well it fits with the existing system (e.g. Ehrnberg & Jacobsson, 1997). A perspective which has provided insights into how physical structures relate to each other is that of *Large Technological Systems*. One of its main proponents is Hughes (1983), who presents the concept of technology as a system with various growth stages. In Hughes' view, technological systems are "messy – both socially constructed and society shaping" (1987: p51). All parts of the system are interdependent and work together to form the system, and when one part moves or changes, the rest of the system must change to accommodate the new configuration. This is also described by Dosi (1982) who proposed that technologies follow a development trajectory. Rosenberg (1994) expands on this discussion and concludes that there are considerable investments on both producer and user sides in the process.

The idea that there needs to be some form of compatibility with already existing structures to embed something new is supported by scholars of the IMP network approach. As Håkansson and Waluszewski (2007) conclude, the less change the new will impose on the old structure, the easier it will be to embed the new. In this context, if a new solution is significantly different from the current resource structure, the resistance to finding a use will be stronger. Also, when resources have a use, they must not only fit with material and tangible artefacts (Håkansson & Waluszewski, 2002; Waluszewski et al., 2009), they also need a fit with immaterial and intangible social structures (Latour, 1984; Bijker, 1987; Bijker & Pinch, 1997; Håkansson & Waluszewski, 2002). Thus, when something new is introduced, the effects are not fully possible to predict because it occurs in relation to a large number of different resources owned and managed by various actors. The systematic combining and interaction between different structures is exemplified by Håkansson et al. (2009: p6):

> To use a car we need a whole set of other resources including roads, fuel, fuel stations, parking areas, workshops and so on. It is not just a set of tangible resources that is needed, but also intangible ones, to provide these resources together with suitable capabilities. Every resource is, in its use, related to a number of other resources. The same is true for the production of the resource. Behind the car there is a well-developed set of advanced companies with highly specialized production and development resources that have been systematically combined to design and produce the car. Thus, resources gain systemic features, both in relation to how they are produced and how they are used. Over time resources are related and developed together, i.e., they "give" each other features of which they can take advantage.

What has been discussed above is the importance of two different concepts when considering how new innovations come into being. One relates to the context in which the new solution is to be used within and the other relates to embeddedness. Let us take a closer look at these notions.

Contextual use and embeddedness

The development of resources in relation to technological development and innovation has been studied by Wedin (2001), Baraldi (2003), Håkansson and Waluszewski (2002, 2007), and Waluszewski et al. (2009), among others. From the view of these authors, the contexts of both embeddedness and use are important factors to consider when resources are developed. As discussed, for something new to be embedded into existing structures requires a certain fit and benefit for the existing structures, i.e. that it can create value for investments already made. An important characteristic of these structures is stability and there is a tendency to protect the existing investments. Thus, in order for a change to occur, it is necessary to understand how it can contribute positive benefits to the existing structure, in other words the use context.

The use context refers to the specific structure in which a resource is used. As a certain resource is combined with a number of other resources and used by several actors there will be an endless amount of possible resource combinations where the applications and features are created in the interaction process. Thus the value a resource will contribute to each user is different, due to variations in goals and what resources it is combined with (see, e.g., Holmen, 2001; Wedin, 2001). For example, a new scientific discovery might generate value for the academic researcher in terms of publishing research papers, filing patents or gaining additional research grants. However, in a business setting the same discovery might not generate any use since it might be too "unrefined" to be able to integrate into a company's development pipeline. At other times, the same discovery ends up as the property of a university's technology licensing office as a marketable intellectual asset. Therefore the value of a certain resource and how it is combined is obviously different depending on which user is considered and in which context it is used, whether it is in a developing, producing or using setting.

Håkansson and Waluszewski (2002) state that, when a resource is used in a certain structure, context-specific features are created as it is confronted with other resources that also

get adapted. Therefore, when a resource is changed it also has effects on related resources in the larger structure, which needs to accommodate that change and be re-adjusted to a greater or lesser extent. The complementarity and adaptation that occur between resources are referred to as embeddedness (Wedin 2001) or "firms' relations with, and dependence on, various types of networks" (Halinen & Törnroos 1998: p187).

One of the earlier attempts to explain embeddedness and business behaviour was by Granovetter (1985), who used the term to describe the social content in economic activity[15]. According to Granovetter, social relations and ties – i.e., embeddedness – influence economic action to a much greater extent than some mainstream economic theories acknowledged. While Granovetter focused on a social dimension, other scholars (e.g., Håkansson & Waluszewski, 2002; Baraldi, 2003) have suggested that there are also important technical aspects to consider. From the social perspective, business activities are embedded into relationships which have effects on the behaviour of organizations and companies. As mentioned above, it causes adaptations between different parties and of the resources that are exchanged and used (Håkansson & Snehota, 1995). The technical aspect is related to the physical structure such as machines, production plants, products and so forth. From the technical side, machines need to work together with other machines and fit with the production structure et cetera. According Wedin (2001), the social and technical embeddedness has consequences for the economic behaviour of the actors involved in the network. The different logic of various actors also adds complexity to how resources are used.

As the contextualization of a resource creates embeddedness into a structure of related resources, it implies that there is a certain degree of inertia related to both stability and resistance to change (Hughes, 1997; Ford, 1998). According to Baraldi and Strömsten (2005), the use of any resource can be complicated by the embeddedness of other resources which limit the possibility of using new ones. This has been explained through the concept of path dependency, i.e., that a certain technological solution has a set path which cannot be left without incurring costs (David, 1985). An example often cited is the QWERTY keyboard, which is considered less efficient for typing than are some other configurations, such as for instance the Dvorak keyboard[16]. However since it has long been the dominating standard and

[15] In the article, "Economic Action and Social Structure: The Problem of Embeddedness" (1985), Granovetter argued that social relations have a large impact on economic behaviour and offered a critique to the lack of understanding of the social dimension in neoclassical economics, and transaction cost analysis.

[16] The reason why the letters on a computer keyboard is arranged in the QWERTY order is that Remington started to use the design for their typewriters in the 1870s in order to avoid the keys jamming together (although this problem does not exist with computer keyboards). Thus it became more popular than its competitors at an early stage and created a fixed path. QWERTY is a prime example of a "lock-ins" in technology and path-

is embedded in established networks, it would be too costly to change. As a result the contextualization causes what some commentators call "lock-in effects" (see e.g. Dosi, 1988). What is important to take away from this discussion of contextualization and embeddedness is that it creates stability but also resistance to change. Given the above background, how can we then analyze how new solutions that are developed outside of producer-user structures, become embedded in an established business setting?

2.2 Analyzing how new solutions developed are interfaced with producer-user structures

The main lesson from the above overview of the business landscape is that it is driven by *interaction* and characterized by *interdependence* and *business relationships*. One important aspect of the interdependence is that it creates effects not only in the dyadic relationship, which has been the smallest common denominator in IMP, but also throughout a network of related *resources*, *activities* and *actors* (see summary of ARA model at note 13, above). The overview has so far provided a general understanding of the business landscape however it is now time to be more precise about what will be analyzed.

This dissertation concentrates on the resource dimension and more specifically on the interaction of resources in a business setting. The fundamental assumption employed by the IMP perspective concerning resources is that they are heterogeneous. The notion of *resource heterogeneity*[17] was early on suggested by Penrose (1959) who argued that a resource is "a bundle of possible services". In other words, it is not the resources per se but the services they create that make them valuable. Alchian and Demetz (1972) expanded on the concept of resource heterogeneity and argued that the reason a certain company performs better than its competitors does not relate to having a better set of resources, but rather through having a deeper understanding of the relative productive value of those resources. In the IMP setting these ideas were adopted by Hägg and Johanson (1982), who proposed that the value of a

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dependence. The explanation is that "switching costs" come in two forms, on one side the switching costs; i.e., the opportunity cost associated with obtaining, installing and learning to use a new technology. On the other side, there are switching costs due to "network externalities", or "external increasing returns". The technology per se is not more efficient when it is more widely employed, but it is more valuable. The more common QWERTY keyboards are, the more useful it is to learn to type on them rather than using the Dvorak keyboard. Hence there are increasing returns for the number of QWERTY keyboards in place, and this is due to the value of the "network" of such keyboards. To depart from that network comes with a switching cost, even if there is no distinct difference between the product and its competitors (David, 1985).

[17] Resource heterogeneity is perhaps best understood in relation to its antonym, resource homogeneity, where it is believed that resources only have one value that does not change irrespective of how it us used or combined. (for a more detailed discussion, see Holmen et al., 2003).

resource depends on how it is combined with other resources. Hence resources alone are not productive and have no value unless they have a use or a function to fulfil in combination with other resources, i.e., forming a network-like structure. In other words, the value can only be assessed when a resource is used and combined with others, that is to say, when *resource interfaces* are created. The value of a resource is impossible to know in advance until it is combined with another. How do we then analyze the interaction between heterogeneous resources?

First we will consider the empirical material in terms of three empirical settings: *developing*, *producing* and *using*. These settings can all be a part of existing business relationships, but they can also be far away from each other. An example of the latter could be, for example, when a research group at a university comes up with a new scientific discovery. In this case it is not certain that the established producing or using structures exist. Nonetheless irrespective of whether it is close or far between development, production and use, each structure related to these activities is characterized by already-made investments in material and immaterial resources. Second, to investigate resource interaction and the creation and emergence of interfaces in the settings and between them, we will also apply a research tool that provides a typology of resources and guidance on how to search for different resource connections. The search tool, known as the 4R model[18], is based on the interaction between four types of resources of both material and immaterial character. Let us now take a closer look at these two different parts, starting with a discussion of the three different empirical settings related to the three kinds of activities; development, production and use.

Three empirical settings: development, production and use

For an innovation to be used it needs to be produced and also developed (Håkansson & Waluszewski, 2007; Håkansson et al, 2009). Accordingly these activities make up three different settings in which an innovation comes into being. Each activity and setting has its own characteristic and function. Thus they need to work together and be able to benefit from each other in order for innovation and economic value to occur. As Håkansson and Waluszewski (2007: p152) note "development, production and use could be analyzed as three related but "independent", and thereby isolated decision". In this particular study the settings are discussed in terms of resource structures related to developing, producing and using

[18] The 4R model is also known as the "resource interaction" model or "4 resource entities" model.

activities. These resource structures are not fixed and are constantly in a state of change, and since they follow different goals they can both hinder and benefit from each other. Below follows a discussion of the empirical based settings[19].

A developing setting: Before a product or innovation can be produced or used it needs to be developed.[20] The developing structures, consisting of material and immaterial resources, are often represented, for example, by academia, research institutes or R&D departments of companies. Given the nature of their activity, that is to say conducting basic or applied research and development, the ideas of use and production are often vague, especially in the case of "radical" innovations. Within the IMP approach, development has generally been studied within existing business structures. What has been found is that it is difficult to create interfaces between developing and the producing-using settings. However, an even greater challenge is when development occurs in a structure outside of the established business setting (Håkansson & Waluszewski, 2002; Håkansson et al., 2009).

A producing setting: The producing structure refers to the material and immaterial resources available to produce a certain product et cetera. The typical producing company is highly reliant on suppliers[21], implying that the amount of existing investments is considerable. Therefore the producing resource structures need to take into account the economic consequences of building in something new. The technical and organizational characteristics of the new have to balance with the economics of production (Gadde & Håkansson, 2001). An important issue is whether the production of a new resource fits into the existing production structure and with the introduction of something new, resource interfaces are central for how new knowledge is being built into a producing structure (Wedin, 2001). The interaction with users is also critical, as they are the ones deciding what will be purchased. As the revenue comes from the users these will have a large impact on the decisions made for production in the business setting (Håkansson & Waluszewski, 2007).

[19] The three settings are referred to as empirical as organizational and physical resources are not a priori categorized in a specific setting. For instance in a model-based view, the development setting is often seen as the academic world, or the so called upstream sector, and the producing-using settings are businesses, i.e. the midstream and downstream sectors. In this particular study the categorization of specific resources into a setting is dependent on the activity they perform, thus in this understanding universities can be users as well as developers, companies can be developers, producers as well as users et cetera.
[20] Although this suggests a linear path, it is not the intention to advocate such a development process. Rather all three structures often co-exist in parallel with each other and can be closely related or far away from each other.
[21] For example, of Volvo's total costs 70-80 percent is derived from purchasing goods from suppliers (Gadde & Håkansson, 2001: p5).

A using setting: In the using structure, the solution is confronted with the users' already existing resources, material as well as immaterial. Thus use is not something which occurs "naturally", it depends to a large extent on what kind of efforts the users want to make to bring in new resources, whether a new machine or a pharmaceutical product. This decision is based on what effects the solution can create on the existing investments (Harrison & Waluszewski, 2008; Håkansson et al., 2009). For example some issues considered by users are: What costs are incurred and what positive economic benefits can the new contribute with?

By investigating the particular characteristics of the different empirical settings, there are various ways the creation of producer-user interfaces around new solutions can be investigated. In this dissertation it will be done by studying how resources become related to each other in a systematic way. A central issue of how resources are developed and value is created is how a specific resource is used in relation to a larger resource constellation. As have been mentioned earlier, there needs to be some level of fit in order to create benefits. To be able to identify resources and investigate the interactions that occur we need a search tool. In this dissertation, resource interaction will be analyzed through the *4R model* developed by Håkansson and Waluszewski (2002).

The 4R model and resource interaction

The 4R model was developed in Håkansson & Waluszewski (2002) to investigate direct and indirect interaction between resources, on the basis that it is possible to catch interdependencies even when they are not represented through direct relationships. The model has been applied to areas such as product, technological, logistics, and industrial development (see, e.g., Wedin, 2001; Håkansson & Waluszewski, 2002; Baraldi, 2003; Gressetvold, 2004; Jahre et al., 2006, Håkansson & Waluszewski, 2007, Waluszewski et al., 2009). The model provides a scheme to classify resources, but is also an analytical tool to investigate how resources are being developed and used in relation to a larger network-structure over time (Håkansson & Waluszewski, 2007).

In the 4R model, resources are separated into four categories where two are mainly tangible or physical: (a) products and (b) facilities or equipment. The other two types of resources are mainly intangible or organizational: (c) organizational units and (d)

organizational relationships. Below is an overview of the four types of resources (Håkansson & Waluszewski, 2002).

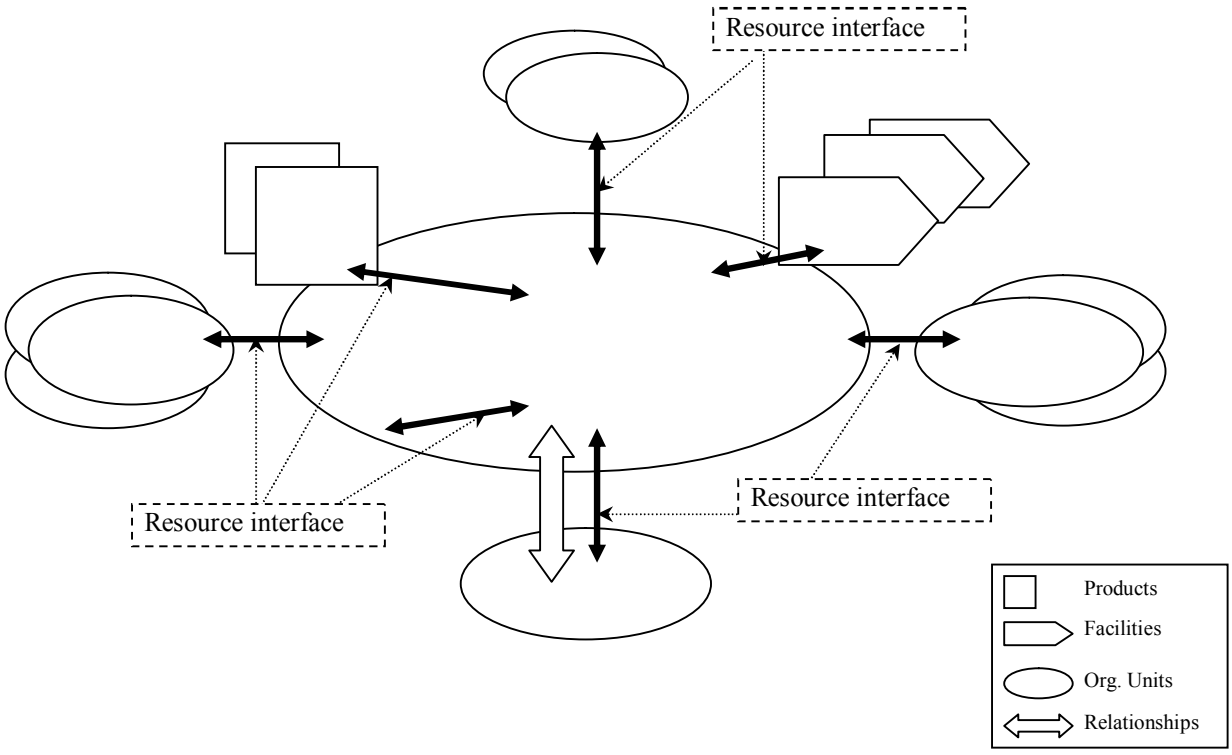
(a) Products: Products are physical artefacts. The features of products are created in the interaction between users, producers and developers. Examples of products are cars, pharmaceutical drugs, and micro-chips.

(b) Production facilities: Facilities are also physical and these are used in the production, modification or manufacturing of products. Examples of facilities are warehouses, laboratories, production plants, factories or equipment.

(c) Organizational units: The organizational units are social in character and include the knowledge of the individuals that make up the organizational units. Examples of organizational units can be companies, authorities, non government-organizations or parts of organizations.

(d) Organizational relationships: Organizational relationships are also social resources and quasi-organizations developed through interaction over time. They connect various organizational units and are developed over a longer period of time as a result of extended interaction.

Figure 2.1: An illustration of the 4R model and interfaces



Source: Modified from Waluszewski et al. (2009)

As can be seen from Figure 2.1, both material (physical) and immaterial (organizational) resources are combined into a larger resource structure, connected through interfaces. In this dissertation attention is directed to the interaction between resources and how they are combined and developed over and beyond time, organizational and spatial boundaries. How the resources affect each other are investigated through the interfaces that are created between resources. The resource structures can also be studied in terms of two dimensions, on an image level and an activated structure.

Resource interfaces

The development and combination of resources takes place within and beyond the borders of organizations, over time and technological fields. Thus it implies that no single actor can have full control over all the resources involved, for example, in the development of a technology. Naturally with a myriad of various resources interacting, where new things are exposed to established structures or existing solutions are introduced in new settings, synergies as well as tensions are created (Håkansson & Waluszewski, 2002). This is a result of various actors having different ways of using a resource depending, for instance, on their capabilities, visions and goals (Håkansson et al., 2009). Consequently it is of interest to understand how resources affect each other and create effects directly as well as indirectly. This can be examined through the study of resource interfaces, which are defined by Strömsten and Håkansson (2007: p29) as follows:

> No resource is used in isolation. Every resource has interfaces to both physical and organisational resources. […] "interface" is defined as "a place or area where different things meet and have an effect on each other".

Thus when a resource is being used it occurs in relation to a larger structure of resources, per definition it is combined with at least one other resource. For example, a machine that is integrated into a research laboratory is often used together with other machines, and operated by a researcher representing an organization. Hence resource use implicitly means an interface directly or indirectly with other resources. By originating from a *focal resource* the interaction with other relevant resources creates a context. The interfaces between resources are essential to study as they inquire into how they affect each other when they are confronted

(Håkansson & Waluszewski, 2002; Baraldi, 2003; Waluszewski et al., 2009). For instance, when a company encounters a new product, what happens to its social, economic and technical features? Or how do different organizations affect the features of a specific physical product? By examining the interfaces between resources, the effects of interaction between social and technical resources can be studied.

A change, such as the introduction of a new resource will naturally have consequences in direct interfaces, but changes also have consequences in indirect interfaces. To take an example, GE Healthcare manufactures various machines for the production of biopharmaceutical drugs and the machines of different scales can be used together easily. The operating system is the same for all machines, and laboratory personnel can learn how to operate new machines from GE Healthcare rapidly if they have prior experience of the system. However, should a customer of GE Healthcare choose to introduce in their laboratory a machine from another manufacturer, there might be problems with compatibility and additional investments would have to be made, to also other machines. Accordingly, the notion of interface management is related to having some kind of fit when introducing something new in existing resource structures. Håkansson and Waluszewski (2001: p3) explain this as follows:

> Along with this flood of stronger or weaker forces trying to create change, many things have to work together. There are production facilities using all sorts of technologies, which have to work – and they have to do it together. There are deliveries of different products that not only have to be on time, but also have to include certain specific features – which have to be stable from one delivery to another. Thus, all these features of resources, which are developed in relation to each other, and activated in certain interfaces, create a need for a co-ordinated activation of resources. The interfaces have to fit together – which means that certain features activated in relation to each other must remain the same over certain activity cycles.

The above quote suggests that the creation of resource interfaces is an organizing process where the actors behind the resources will, at least to some extent, try to control and manage the use process. As Wedin & Waluszewski note (2003: p4) resource combination "becomes an issue of interaction between those representing direct and indirect resource interfaces".

Image level and activated structures

To analyze resource interaction processes, there are two relevant dimensions to consider: an *image level* and an *activated structure*. The activated structure reflects how resources are used in material processes – that will say how they have been combined and adapted to each other in terms of resource ties, actor bonds and activity links (Abrahamsen & Naude, 2008). The image[22] level is based on *idea structures*, including knowledge of different technologies as well as different actors' problems, goals and ambitions. This structure is never stable, due to the continuous development of new knowledge, and goals (Håkansson & Waluszewski, 2002). A similar division is also expressed by Brunsson (1989: p168, quoted by Håkansson & Waluszewski, 2002) which distinguishes between "a system of thoughts or ideas and a system of action. The idea system defines what is handled in mental and communicative processes, and the action system what is handled in material processes".

To study the two dimensions allows us to investigate whether new solutions materialize into use in an activated resource structure, or mainly appear as ideas among organizational actors (Brunsson, 1989; Czarniawska & Joerges, 1996). The distinction between images and activated structures including an analysis of their relation, provide an understanding of how changes occur. It enables us to capture not only what is already materialized but also how the activated structures are affected by what is communicated through images (Waluszewski, 2004b). For instance how aware are the actors behind the resource interfaces? Are they the

[22] Images on how to use and develop resources come from various sources such as individuals, businesses, non-governmental organizations and policy organizations. The images can be based on knowledge acquired through experience and be of more tacit nature. Sometimes the knowledge is well specified in manuals, formulas and so forth. In these cases images are developed in close relation to already activated structures, but idea structures can also be developed far away and by actors that are not participants in the development of the physical structure. Thus images are fragments of how a resource have been or can be utilized (see, e.g., Håkansson & Waluszewski, 2002). As images are created by many actors there can also be a large discrepancy between different images of a resource for which there does not need to be a fit (Sahlin-Andersson, 1996). Idea structures can be wide-ranging, and include conflicting ideas about how to combine and use resources (Håkansson & Waluszewski 2002; Czarniawska, 1996). One reason for the discrepancy is that actors using the same resource often use and develop it in different contexts. When different logics dictate the understanding of how resources are to be used and developed, it causes contradictions which might complicate changes in the activated structure (Håkansson & Waluszewski, 2002). Furthermore, as Håkansson and Waluszewski (2002) state, ideas change more quickly than the activated structure. While the image level can be based on several contradicting ideas, the activated structure on the other hand requires a fit between resources. Adaptations are created between resources over time and changes need to be accommodated by the larger resource structure in direct as well as indirect interfaces (Wedin, 2001; Baraldi & Strömsten, 2005). Why are idea structures important if they might conflict and cause ambiguity? According to Håkansson and Waluszewski (2002), the idea structure is important in relation to the activated structure in two ways. First, ideas are interpretations of activated structures, providing interpretations of why things work as they do. Second, the idea structures are also a source for making deliberate changes in the activated structure. They provide a point of origin from which changes to the activated structure can be made. Hence ideas are important to initiate change in an activated level that promotes stability but, as discussed, they have to be linked and built into an existing structure in order to materialize.

result of a conscious, central planning or are they are mutually organized through a conscious interaction process?

Summarizing the framework to analyze resource interaction and how new solutions developed gain producer-user interfaces

This chapter began with outlining a business landscape, which is characterized by interdependence and the formation of relationships between different organizations and companies. Interaction was identified as the driving force behind these developments. The common empirical experience of how innovations or new science-based resources come into being in such an environment is that it is both complex and non-linear in character. By relating to notions such as embeddedness and the contextual use of resources some challenges were exemplified. For example, when something new is introduced it needs to fit with existing resource structures, where there is a tendency to protect the established investments, in order to generate any benefit.

The picture of the business landscape that has been described from mainly the perspective of the IMP network approach is different from the picture which dominates in contemporary policymaking. From the policy perspective, the emphasis is concentrated on how to produce and transfer relevant scientific knowledge to the business world. The difficulties of the use of new solutions developed outside the existing producing-using setting, whether science-based or not, have not been a focal issue in policy analysis. This issue is instead in focus in this dissertation. As was discussed in the introductory chapter, the scope of the research is to investigate how resources from developing structures, become produced and embedded in using settings. To catch these processes, the analysis is made of three different empirical settings; developing, producing and using. These can be closely related to each other as well as quite distant. The research tool used to analyze resource interaction within and between these settings is concerned with four types of resources; products, production facilities, organizational relationships and organizational units. The resource interfaces that are created between them are central for the analysis of development processes. Since the creation of new developer, producer and user interfaces includes trial-and-error learning and adapting processes, it is necessary to study possible resource combinations and how they affect established interfaces.

The analysis will be made on a larger empirical study starting with a case which is considered to be a successful policy-created industrial network by policy organizations, industry leaders, and researchers – namely, the Taiwanese semiconductor industry. The policy interpretation of this development has become a major inspiration in modelling other industrial endeavours in Taiwan. The most notable example is the biotechnology industry, which is considered in the second part of the empirical study. How the empirical study was constructed and the methodological considerations will be discussed in the next chapter.

CHAPTER 3
RESEARCH METHOD

In this chapter I will describe how I conducted the empirical study and discuss the methodological considerations of this dissertation.[23] A typical description of how to carry out qualitative research is first to identify a problem, then review existing literature, specify a purpose, collect data, analyze the material and lastly to report and evaluate the results. As will be obvious, this investigation has not followed that template. During the course of collecting data I simultaneously analyzed the material, reviewed literature, identified research problems and thus gradually arrived at the research design through an iterative process. Even though the empirical direction of the study has changed several times, the general interest in the relation between policy endeavours and business development has remained stable. Furthermore, the methodological and theoretical point of reference has been fixed. It has been the 4R model that has broadly guided the data collection, and through a search for resources and related interfaces the context for the empirical study was created.

3.1 A qualitative study influenced by IMP research traditions

The next section deals with the research design and how the material collected became a coherent study. To provide insights into this process I will continue with discussing the methodological approach influenced by the IMP research tradition. According to Håkansson and Waluszewski (2002, 2007), the knowledge creation process is interdependent with its context. As the authors suggest, research is made with the *stamp of research tools*, i.e., the pictures that are created through applying a certain theoretical perspective are fragmental and heavily dependent on the models used. In other words, it is not possible to catch either a true or a full picture of reality, what can be caught are only fragments of the empirical world. This is explained by Snehota (1990: p11) as follows: "Concepts, frameworks, and theories are always reductive with respect to the phenomenon because they exclude certain aspects and

[23] The focus is on describing the research process and the task of trying to find an appropriate label to the research approach I leave to others.

dimensions of the phenomenon as irrelevant for the interpretation". Or, as Håkansson and Waluszewski (2002) argue we can only see what the research tool investigates.

Consequently different theoretical perspectives and their associated models can provide substantially different but still equally plausible explanations of an event or phenomenon (Heider, 1988). Through this understanding it becomes an important issue in qualitative research to persuade the reader that the research process and findings of a study are plausible. To this end, Merriam (1988) suggests that qualitative research should be judged as credible and confirmable as opposed to valid and reliable. Lincoln and Guba (1985) argue along a similar discourse and discuss quality in relation to trustworthiness and four interrelated criteria: *Credibility*, meaning that the research should be believable from the perspective of the participant in the research; *Transferability*, by doing a thorough job of describing the research context and the assumptions that were central to the research; *Dependability*, to account for the ever-changing context within which research occurs and; *Confirmability*, which will determine how the results could be confirmed by others. To provide insights into these quality criteria, with regard to this dissertation I will continue with presenting a transparent account of the research process, design and data collection. Through this description readers can pass their own judgement on the plausibility of this investigation.

Creating a context – Starting with the investigation of a biotechnology tool as a focal resource

This dissertation has its origin in a larger research project[24] that began in July 2004. The general scope, to investigate *the creation of economic value and the role of science and industry in this process*, was based on the observation that in the OECD world, policy organizations and governments are taking increased measures to develop growing and dynamic companies and regions through the transfer of knowledge from academia to the business world. To investigate this phenomenon, the research questions were concerned with (a) what principles policy rests on and (b) how scientific and other knowledge is embedded in new commercial resources (Waluszewski, 2004b).

The empirical part of the study was carried out in three different contexts: Silicon Valley in the US, Shanghai in China and Taiwan. In all contexts, a common "probe" was used to investigate the embedding of science-based resources in the business world. This probe was

[24] "Uppsala Biotech cluster. Seven decades of international embeddedness", conducted at Uppsala STS Center, with Alexandra Waluszewski as the research coordinator (www.sts.uu.se).

a state-of the art chromatography system[25], ÄKTA Pilot manufactured by GE Healthcare. The rationale to choose this system was because it was used for both industrial and laboratory-scale production, providing an opportunity to investigate both scientific and business activities by following just one machine. In other words, ÄKTA Pilot could provide information whether the activities the customers were involved in where of developing character or if they had also reached producing and using stages. Since GE Healthcare[26] was a world leader in developing and manufacturing biotechnology instruments, it also offered the chance to follow ÄKTA Pilot in a number of countries.

The decision to choose Taiwan was because the Taiwanese government was strongly promoting biotechnology. Taiwan was therefore an interesting context to study, but the decision was also partly out of personal interest because of my cultural background and knowledge of Taiwanese and Chinese languages. In addition I had been accepted as a visiting researcher to National Taiwan University at the commencement of my doctoral studies. In September 2004 I made my first research trip to Taiwan and stayed for five months. Data was gathered related the use of the ÄKTA Pilot and on the development of the Taiwanese biotechnology industry in general. During this time I had several meetings with representatives of GE Healthcare which gave me an overview of the company's business activities in Taiwan including the embedding of ÄKTA Pilot. I identified seven chromatography systems sold to Taiwanese customers (at two companies, two research institutes and a private university). The information I received was mainly on how the customers used the system. For example if it was used for development purposes, or if the developed solutions were also produced and used in a larger scale. The investigation eventually resulted in a research paper authored with my research group at the beginning of 2005[27].

[25] The reason for choosing ÄKTA Pilot was to find out what was going on under the surface of these hyped biotechnology regions by following a tangible product. The ÄKTA Pilot is a machine for protein separation used in the production of pharmaceutical drugs. Over 90 percent of all biopharmaceuticals approved by the FDA use one of GE's products at one stage of their development. Since the ÄKTA Pilot is the only GE chromatography system which bridges the step between laboratory and production (i.e., small and large scale production), it was deemed to be an appropriate probe to investigate and gain a picture of how the biotechnology industry within the area of biologics/pharmaceuticals had developed.

[26] GE Healthcare's in Uppsala was established through the acquisition of Amersham Biosciences in 2004. Amersham had, in turn, acquired the successful Uppsala-based company Pharmacia Biotech in the 1990s. For an extended account of the development of Pharmacia, see, for example, Andersson (1996) and Waluszewski (2003).

[27] Presented at the IMP conference in Rotterdam 2005, the title of the paper was: "How can a biotech tool reveal what is going on under the surface of three hyped biotech regions? The embedding of ÄKTA Pilot in the US, China and Taiwan" (available at www.impgroup.org).

As I had already set a path with the ÄKTA Pilot study and devoted quite some time to collecting data, the plan was to continue with this empirical inquiry. However I had encountered several problems along the way and making it into a dissertation project was complicated. A considerable problem was the lack of access to the user units of ÄKTA Pilot in Taiwan, but also the fact that most of the customers did not actually use the system. Although an interesting empirical observation in itself, this made it difficult to continue the investigation. However, by following ÄKTA Pilot and GE Healthcare in its capacity as one of the major biotechnology equipment suppliers in Taiwan and the world, I had learned more about the Taiwanese biotechnology industry. The picture that arose was different from that offered by government statistics and other official sources. For example, the official statistics were displaying a vibrant Taiwanese biotechnology industry, with an increasingly growing number of companies. In government statistics from 2004, 296 biotechnology-related companies in several different technological fields were identified (MOEA, 2004). GE Healthcare, however, had only three stable industrial customers, including two research institutes, out of all the large number of companies in the industry. Even though the government was heavily supporting the industry GE Healthcare did not expect that this situation would change much in the near future.

Following a policy-driven attempt to develop a vaccine against Japanese encephalitis

The problem of gaining access to all the users of the ÄKTA Pilot led me to re-direct my study. At the time it seemed more relevant to follow and concentrate on the three main industrial customers of GE Healthcare. One reason was their regular business exchanges with GE Healthcare. Another reason was that these customers had development projects in the pipeline and therefore offered some examples of actual business interaction for me to focus on.

The three customers were: a public research institute, the Centers for Disease Control (CDC); a semi-governmental research institute, the Development Center for Biotechnology (DCB); and a private company, ADImmune. All three organizations had purchased an ÄKTA Pilot and when taking a closer view at their research and business activities I found out that they were all, in one way or the other, involved in vaccine projects. In particular, they were part of a network created by the Taiwanese government to develop a vaccine against Japanese encephalitis.

Although I had identified this network, at this early stage of the research process it was not very clear what my empirical study was about or how I would use the empirical field to catch the policy attempts to create business development. The starting point had been the ÄKTA Pilot, and the 4R model was the search tool looking for resource interfaces related to policy as well as to business. While attempting to map the extended resource network I encountered difficulties with gaining access to the users of the focal resource ÄKTA Pilot. Nevertheless, by searching for related resource interfaces I had come across a network consciously created by the government, involved in the development and production of a vaccine against Japanese encephalitis. The vaccine project became my focus during my second research trip, lasting from February to August 2005.

A focus on liposome-based biopharmaceutical drugs

Throughout the research trip I continued to collect data and information about the Taiwanese government's ambition to develop a biotechnology industry. With the help of GE Healthcare I was able to arrange a meeting with the DCB. The picture of how the government was actively trying to create an industry by engaging research institutes as the bridge between public research and industry started to become clearer. Through my contact at the DCB I was informed about the Biotechnology and Pharmaceutical Industries Program Office (BPIPO), a government organization commissioned to direct and implement the government's development initiatives in biotechnology. As this organization seemed to be an important actor in coordinating biotechnology development I wanted to learn more of their activities and my next few meetings were with representatives of the BPIPO at the newly established Software Park in the Nankang District of Taipei.

The Nankang Software Park was built for the purpose of developing and hosting companies, research and policy organizations related to the Twin Star industries; Digital content and Biotechnology. I was invited to visit the biotechnology incubation center at the Nankang Software Park, which had been established for the purpose of assisting promising Taiwanese biotechnology companies. Through my own observation there did not seem to be much activity at the incubation center but I was offered the opportunity to visit the only company that had any visible activity at the time. The name of that company was Taiwan Liposome Company (TLC), a university start-up enterprise engaged in drug development, founded in 1997. Initially it was not my intention to include this company in my study, I just

wanted to find out more about the activities of the incubation center. However, since I was granted access and the company had already been in existence for a few years and had interesting business projects in the pipeline, I decided to continue interviewing representatives of the company. The story that emerged provided a different angle of the Taiwanese government's role in aiding biotechnology companies. In comparison with the vaccine project, TLC and the commercial field of liposome-based biopharmaceutical drugs had encountered some reluctance from the government to provide assistance. By following the development of liposome-based drugs in Taiwan, which included domestic as well as international companies and research organizations with development stretching as far back as the 1960s, a larger picture of biotechnology development in Taiwan was emerging. The vaccine and liposome cases were two contrary development stories. Both had been acknowledged by policy in Taiwan, but received different kinds of government support. The outcomes of the two projects were also very different. The ways vaccines and liposome-based biopharmaceuticals had been supported and developed opened up the issue of the role of government policy in the creation of new business resources.

A background to the roots of the development model – The Taiwanese semiconductor industry

Already in my first research trip I visited Hsinchu and the Industrial Technology Research Institute (ITRI), the birthplace of the Taiwanese semiconductor industry. In the interviews I conducted there I was told how the semiconductor industry had emerged with the aid of government policy and what role ITRI had played in the development process. At the time this information did not seem all that relevant with concern to the ÄKTA Pilot study. However as my study progressed I became increasingly aware of the emphasis placed on the dominant role of the government in developing a biotechnology industry in Taiwan. With this understanding I decided on my third research trip, extending from September 2005 to February 2006, to concentrate my efforts on learning more about the government's industrial policies. It seemed to be a commonly accepted view that it was the government that had created the Taiwanese semiconductor industry. The policy plans aimed at creating a biotechnology industry were therefore heavily influenced by the development of the semiconductor industry.

By the time I had finished three longer research trips to Taiwan, a cohort of empirical inquiries had been made albeit still somewhat dissimilar. Nonetheless all of them revealed at least a certain degree of government involvement, thus encouraging me to find out more about the government's development model that was believed to have created the Taiwanese semiconductor industry. To expand my understanding of how such a development had occurred would also be helpful for me to understand the emergence of the biotechnology industry in a larger context.

Two major issues were at focus for my search for more information. The first one was related to elucidating the common understanding of how the semiconductor industry emerged and the main features in this emergence. The second was concerned with the observation that the largely homogenous development story that was presented to me by a large number of interviewees and unrelated sources seemed fairly unquestioned. The template, which had been presented to me, was considered to have created the semiconductor industry. Although the general consensus was that it was not working very well for the biotechnology industry. This observation led me back to the original research aim of the project, to investigate the creation of economic value and the role of science, policy and industry in the process. The main issues of interest became how innovations appear when approached from an interactive perspective (i.e. from the view of IMP and resource interaction).

3.2 Constructing the empirical study

The previous section has described the development of the empirical study, including the direction of the different phases and the reasons for redirecting the investigation. The major phases of the empirical study are summarized in Table 3.1.

Table 3.1: Phases of the empirical study

	Phase 1	**Phase 2**	**Phase 3**
Studies	• The Taiwanese biotechnology industry through the eyes of ÄKTA Pilot • The semiconductor development model (the government account) • Biotechnology in Taiwan an overview	• The Japanese encephalitis vaccine • Taiwan Liposome Company	• The emergence of the Taiwanese semiconductor industry revisited (an extended account)

The first phase (1) started with investigating the embedment and use of ÄKTA Pilot and also provided a general overview of the biotechnology industry in Taiwan. Through the ÄKTA Pilot study the Japanese encephalitis vaccine project was identified and used to illustrate how the Taiwanese government was trying to create a vaccine industry. Not directly connected with the ÄKTA Pilot but to one of GE Healthcare's major customers was Taiwan Liposome Company, a company developing and commercializing liposome-based biopharmaceutical drugs. The studies of the vaccine and liposome projects made up the second phase (2). In the third phase (3) I re-examined the emergence of the Taiwanese semiconductor industry. With this overview, the way the empirical study was constructed and what it is about will now be presented.

Before discussing the rationale behind the organization of the empirical study, I will first consider some methodological issues concerning case studies. In the IMP context, case studies[28] have been heavily utilized to exemplify diverse empirical phenomenon. According to Easton (1995), the usefulness is due to the richness of the picture produced by case research. The approach is suited to handle the complexity of network links amongst actors and can be employed to trace the development of network changes over time. Furthermore case studies are suitable to use when exploring interaction and relationships (Dubois & Araujo, 2004). However a problem which is often encountered is that the rich empirical content leads to unfocused descriptions and thus results in "weak" conclusions, i.e., saying a lot about very little (Easton, 1998).

How to create order out of rich empirical material can thus be a cumbersome task, and in order to do this there are several possible approaches. For example, Ragin and Becker (1992) recognize two main approaches, based on deductive and inductive logics respectively, to construct cases. First, the "variable oriented approach" starts with identifying a problem, followed with the specification of relevant variables and then trying to match those with theoretical concepts. Second, the "case oriented approach" where the case and not variables are put into focus. Other researchers, such as Dubois and Gadde (2002), suggest an approach referred to as "systematic combining". This method relates to an iterative process where the framework is successively developed, partly as a result of unanticipated empirical findings, and partly from theoretical insights gained in the process. In this view the process is not inductive, but neither are the empirical findings adjusted to fit certain theoretical conceptions.

[28] A case study is an empirical enquiry that investigates a contemporary phenomenon in its real life context, especially when the boundaries between the phenomenon and the context are not clearly evident (Yin, 1994).

Although none of these approaches are fully applicable to the construction of the empirical study in this dissertation, they provide guidelines on how cases can be constructed. For instance, an important lesson is that the theoretical framework, data collection and analysis evolve simultaneously (Dubois & Gadde, 2002). Hence, what a case is about will not be known until the end stages of the research as discussed by Ragin & Becker (1992):

> Researchers probably will not know what their cases are until the research, including the task of writing up the results, is virtually completed. What it is a case of will coalesce gradually, sometimes catalytically, and the final realization of the case's nature may be the most important part of the interaction between ideas and evidence. In short, Becker wanted to make researchers continually ask the question "What is this a case of?". The less sure that researchers are of their answers, the better their research may be. From this perspective, no definite answer to the question "What is a case?" can or should be given, because it depends (Ragin & Becker, 1992: p6).

Similarly Dubois and Araujo (2004) note that: (1) neither the phenomenon nor its context are necessarily known prior to starting the research; (2) simple problems related to apparently minor changes are often arbitrary starting points of a research project; (3) the task of the analyst is often to construct progressively the context and boundaries of the phenomenon, as theory interacts with empirical observations. With this description what a case is about will usually not be evident until the later stages of the research. This understanding is also quite important for the study of networks in the IMP framework. From the IMP perspective there are no objective boundaries to networks, thus making it difficult to define and delimit them. The chain of consequences from one action usually extends over a number of relationships and interfaces over an extended period time. The delimitation of a network is therefore affected by both the aim of the study and the starting point of the analysis (Ford et al., 2002). Consequently in the context of resource interaction, the identification of the resources that are important is a matter of choosing a focal resource through which ties to other resources can be identified and whose importance is decided by the research purpose. In the search for resource interfaces there are no ex-ante distinctions made concerning technological sectors, spatial or organizational borders. Instead the focus is on the search for related resource interfaces that occur across various technological, spatial and organizational fields (Strömsten & Håkansson, 2007). With this background I will now continue to describe how the empirical study was constructed and what it is about.

What is this empirical study about?

The content of this dissertation has been based on two points of origin. Theoretically the foundation was the IMP network approach, with a focus on resource interaction. Empirically it was initiated with a study of the use of ÄKTA Pilot to investigate the development of biotechnology in Taiwan. However, as the empirical study developed and new material was collected new issues also came to prominence (as described in section 3.1). Initially the motive was to investigate a fragment of the Taiwanese biotechnology industry and provide an interpretation of what was happening beyond what was expressed in government plans. As I continued the study, the repeated references to the Taiwanese semiconductor industry and its influence on the Taiwanese government's industrial policy became increasingly evident. Eventually my research design came to incorporate an investigation of the industrialization of two technologies; semiconductors and biotechnology. These were obviously two different scientific and technological sectors but they were connected through the search of related interfaces. As mentioned earlier, there were no ex-ante distinctions made concerning technological sectors, spatial or organizational borders, instead the concentration was on the search for related resource interfaces.

Although the empirical content of this dissertation has changed, during the course of the empirical study, the general interest in the relation between policy and business, as well as the theoretical approach has been fixed. Throughout the whole research process the theoretical focus has been the IMP network approach and the 4R model. Concepts and notions within and related to the theoretical framework, used to explain the phenomena investigated, have been selected through an iterative process as new research issues and material emerged. Furthermore the research scope of this study was not at any point intended to be centered on an investigation of the development of the Taiwanese biotechnology or semiconductor industries alone. Nor was it an attempt to find what was wrong with the semiconductor model and "improve" it to better translate into biotechnology development. By originating from a focal resource I wanted to investigate how resources were developed, produced and used in a business setting. Through this research design the empirical material eventually emerged into one consistent study consisting of four parts. Next I will continue with discussing the organization of the various parts and the reasons for this arrangement.

Due to the rich empirical material it has been a complicated process to structure this empirical study. Of course there were several ways in which the empirical study could be organized in order to have a clear logic. For instance, one could follow an inductive approach

and keep the original outline, according to the way the data was collected, or one could order the empirical material to suit the original research aims and questions. Neither of these arrangements did justice to the empirical material or the analytical framework. Eventually the empirical material was given priority, but to make it more clear, some re-modelling of the empirical study was done. This involved giving the study an emergent character, in which each chapter was telling a story, including identifying questions and providing an increased understanding of the research scope. Each empirical chapter is also concluded with a summary informing the reader of the important themes of the chapter. Thus it will be evident that they all bring different pieces to a puzzle and emerge into a consistent investigation in the end.

The structure of the empirical study is separated into four interdependent parts. The empirical study which is unfolded over the next four chapters begins with an account of the emergence of the Taiwanese semiconductor industry. Chapter 4 is divided into two parts. First (4.1) an interactive empirical account of the semiconductor development is provided. Thereafter (4.2) a policy interpretation of the development is outlined. This interpretation has also served as a template for the correct way to breed new science and high-tech based industries in Taiwan, most notably biotechnology. The manner in which the Taiwanese biotechnology industry has emerged and the government's participation is discussed in chapter 5. This chapter also describes the policy model of how to develop biotechnology in greater detail. To learn more of what happens under the surface of this development model two contrasting cases are presented. The first, described in chapter 6, relates to the development of the vaccine against Japanese encephalitis. The second case, presented in chapter 7, investigates the development of liposome-based biopharmaceutical drugs. Before we start with presenting the empirical chapters the data collection process and sources used will be described.

3.3 Sources and data collection

For the empirical research I have spent an extensive period of time in Taiwan, collecting data and battling field issues such as gaining access to companies, organizations, people and other relevant study objects. The collection of the empirical material started in September 2004 and went on until early 2009. During this period a number of different types of data including oral and written sources were gathered. In addition to my research trips to Taiwan I was also a guest researcher at the Research Center for Advanced Science and Technology, in the Department of Intellectual Property Law, University of Tokyo, between April 2006 and March 2007. This visit gave me an opportunity to learn more about technology transfer, intellectual property rights and university-industry relations. The research trips to Taiwan and Japan have greatly aided my understanding of the research topics related to this dissertation.

My knowledge of Chinese has been helpful as I have not needed a translator when arranging meetings, making travel arrangements and conducting interviews. Furthermore some of the material such as newspaper articles, statistics and government documents that I have used has been in Chinese. Although I speak Chinese, the research process has not been entirely without friction. There have been misunderstandings, some due to cultural differences others related to language. However my prior experience of living in Taiwan most probably shortened the time I needed to become accustomed to the appropriate way of conducting research there.

An issue which was problematic during my field studies was getting access. Many times it took several attempts and a period of weeks before an interview or meeting could be scheduled, but with patience, and the more contacts I established the easier it became. Thus the amount of time I spent in Taiwan for research was necessary to be able to identify and to meet the representatives of the resource interfaces I had identified. Getting in contact with representatives of various companies and organizations was mostly a problem at the initial stage but since interviews were many times my main source of information, this was troublesome. To get respondents to talk about a development they considered a failure was also something I experienced as problematic at times. As discussed previously, these problems strongly influenced the design of this dissertation. However I cannot make any general statements about whether these experiences are typical of doing research in Taiwan, rather this is an account of how I experienced the research process and the data collection process. Although interviews were a major source of information I have also extensively used

other oral and written sources to build the empirical study. The next section will discuss how these have been used.

Data sources - Methodological considerations

With the different data sources I have been able to get diverse pictures of industrial, business and technological development in Taiwan. This part will talk about the role and use of different data sources in relation to the empirical study. I will do this by first discussing some general methodological considerations concerning various sources. Thereafter I will give an overview of the data sources, classified into *oral* and *written*. What is included in the respective categories will be discussed later in this section.

The choice of sources has been related to circumstances such as time period, the phenomenon investigated and the availability of information. To take an example, there is rich written documentation of the Taiwanese semiconductor industry in terms of historical accounts, media coverage, industry analyses and statistics. A part of this is due to its longer history but also related to the fact that the industry has been considered an economic success. In the case of biotechnology in Taiwan the information is less abundant and most of it is published by the Taiwanese government or organizations related to policy. The nascent character of the industry made it difficult sometimes to find written records of certain events and to gain industry data in those cases I mostly gathered information from oral sources. For instance, the Japanese encephalitis vaccine development project that I followed had little public documentation; therefore I initially based that study on interview data. Later I supplemented the first-hand accounts of the interviewees with additional written information of vaccine development using policy documents, government websites and general industry data.

According to Håkansson and Waluszewski (2002), interviews are one of the most valuable sources of information to understand interaction processes. With the use of interviews, there are however concerns related to bias and interpretation, for example as Williams (1964: p339) explains: “Interview bias is likely to occur as a result of some motivation on the part of the respondent or interviewer”. The goal in this dissertation is nevertheless not to eliminate bias but rather to be aware of it and present it in a clear and organized way.

Actions aimed to manage qualitative data may include appropriate critique of sources, storage, and frequent reviews of data quality and interpretation (Wolcott, 2001). For higher credibility, data collection and management could include coding immediately after the interview and review of data that are time- or memory-sensitive (e.g., interviews and observations). To enhance data validity, interviews are often recorded electronically and transcribed. A benefit of not recording, on the other hand, is that it might make the respondent more willing to discuss sensitive issues. The problem which might arise instead is that some of the respondent's answers are not documented. The interviewer also takes notes on what she considers to be important, and much can be left out and forgotten. Methods that can increase credibility include multiple interviewers, post-interview debriefing and follow-up interviews (Holstein & Gubrium, 1995). In addition, as Czarniawska (1998) notes, documents can also be used to deepen the picture given through interviews.

The function of the written sources should be clear to the researcher. For instance, assembling a number of different sources conveying the same thing, for instance through triangulation, does not necessarily imply that it is more correct, instead the researcher might risk ending up with a quasi-deductive approach (Easton, 1998). Furthermore, as discussed by Bryman (1989: p198), "documents are rarely neutral entities", as they are created in a social context with a certain role and function. Similarly as interviews represent the opinions and views of respondents, documents reflect what the author believed was right, or they reflect a certain opinion which the author wanted to convey at the time.

Hence in this study an important consideration, as mentioned, is how to acknowledge bias rather than eliminate it. As Håkansson and Waluszewski (2002) confirm, there is no single absolute answer or picture. In this context, both the oral and written material has brought forward varied views of development processes and events. These represent the opinions and beliefs of the sources in a certain context where one is not necessarily better than the other. An important aspect that Håkansson and Waluszewski (2002) point out is that it is more relevant to ask what function and form the different sources have. With this background I will continue discussing the sources and what function they have fulfilled in the research process.

In the subsequent section I will discuss the data sources in relation to the empirical study as a whole. Although it consists of four different parts, the data collection has not been strictly separated with regards to these, as there has been an overlap of the data gathered throughout the whole study. Another commonality is that a combination of oral as well as written sources has been used for all parts. For example, to illustrate the biotechnology

development model (in chapter 5) and the background to its rationale, I used journal articles, historical accounts as well as policy documents and information from government websites to create an account. I also relied on interviews to interpret and form the views of policy and the government. The study on Taiwan Liposome Company (chapter 7) was mostly based on interviews. In addition I was also presented with a number of documents like investor prospectuses and other information for investors, and newspaper articles. This was supplemented with articles and texts on liposome research et cetera. The development of the Taiwanese semiconductor industry (in chapter 4) was constructed by using journal articles and historical accounts, interviews and policy documents. The interviews gave me an overall picture of the perceived development and to deepen this story I used written sources where the main bulk of information came from journal articles. The next section begins with an overview of the primary sources (e.g., interviews, observations, presentations and speeches), followed by the secondary sources (e.g., policy documents, historical accounts, newspaper articles and journal articles).

Oral sources

The oral sources include interviews, discussions, observations and speeches. The sources were collected during three longer field trips, ranging up to six months, in Taiwan. Starting in September 2004, I spent more than a year and a half in Taiwan conducting fieldwork. The oral sources have been mainly used to provide first-hand accounts of development processes. Some interviews were also conducted to gain an increased understanding of the scientific and technological fields examined in this study. The overview of the oral sources will be divided into two groups; interviews and others.

Interviews: A main source of information for this dissertation has been interviews. 120 interviews were made during the course of three years with 75 different persons (see interview list in appendix 2). The average duration of the interviews was approximately one hour (ranging from 30 minutes to two hours) and the majority, 82 interviews were conducted in Taiwan, while the other 38 interviews were conducted in Japan and Sweden. Of the total number of interviews, 30 were made solely in order to learn more about certain topics in biotechnology, technology transfer or semiconductor technology.

The persons interviewed had different organizational associations including policy organizations, universities, research institutes and companies. The aim of choosing respondents was not to gain a fair representation of the industry or a certain organization. The interviewees identified were chosen to provide: (a) voices on the resources identified throughout the study, and (b) a general understanding of various fields (e.g., biotechnology, semiconductors and technology transfer to mention a few). I identified possible interviewees mostly through referrals but also through searching on the internet. After finding a suitable respondent, the initial contact would usually be in the form of an email or a phone-call to find out if they were interested and available for an interview. In some instances, during the actual meetings, interviewees also invited colleagues to join them in the interview or asked me to interview other people in their company or organization. Due to this, on more than a few occasions I spent half a day or more at a particular company or organization. In most of the cases the interviews were a one-time event, but follow-up interviews were also conducted with a number of key individuals.

The general interview process went according to the following three steps: planning; execution and; post-interview documentation and evaluation. Planning is an essential part of the process as the way we interview and the questions we ask will influence what can be found out of what others feel and think about their worlds (Rubin & Rubin, 1995). As discussed by Holme and Solvang (1997), interview schemes specifying general topics of interest and using open-ended questions can be effective in assessing interviewees' assessments of important concepts and issues, their beliefs and values.

Before each interview, I drafted a general interview guide, with a set of questions, based on whom I was interviewing, my understanding of the important themes and the overall study objectives. The interview schemes, which came in several versions, were however not followed strictly but only used as a rough guide for topics to be covered and questions to be asked. All interviews were made face-to-face, mostly in English but also in Chinese or Swedish. They were planned to be semi-structured in character, i.e. not open conversations but neither strictly following a pre-made guide. Sometimes the interviews turned into quite informal conversations and at other times they were formal. This depended partly on the atmosphere and interaction between me and the interviewees and to some extent also the time I had at my disposal. Primarily I wanted to catch the respondents' own comprehensions of the topic discussed. Through the interviews I wanted to encourage the respondents to describe their experiences in their own terms and to give rich and detailed descriptions of their work, expectations, views and perceptions of a certain phenomenon.

In the majority of interviews I took notes and mostly without audio recording. Only a limited number of interviews were recorded and transcribed. Recording of course provided a more accurate account of the respondents' answers but was more time-consuming and in addition not all interviewees agreed to be recorded. To be able to remember as much as possible and provide an accurate account of what the respondent said, I would sit down immediately after the interview and summarize the main points and my impression of the interview situation. Thereafter I would send the summary, or the parts of the text where the respondent's opinions or facts were expressed, and quotes used, to the respondent for approval. If I had the opportunity to have a follow-up interview I would also discuss with the respondent what I believed were the main points of the last interview and if I had correctly understood what had been said. Through these measures the information from the interviews was, to the best of my knowledge, consequently accurate.

Other oral sources (including speeches and presentations at seminars, workshops and conferences): Participating in the various events mentioned in this section contributed to my understanding of the phenomenon studied. These oral sources were collected through observations, listening and taking notes. During the speeches, presentations and lectures at conferences, workshops and seminars, there were no opportunities to really interact with the speakers besides a question time afterwards. I took notes on what was presented and what I observed. Another important source of information was workshops, information meetings, various conferences (press, academic, business) and seminars that I attended. The topics that were covered during these gatherings included issues related to biotechnology development (scientific as well as business), intellectual property and industry-industry cooperation. By attending it was possible for me to observe and listen to discussions concerning current issues and it gave me information which was helpful for my research. Below is a description of some of the events and activities in which I took part.

In September 2005 I was a participant at the Novartis Biotechnology Camp, a three-day workshop in Taipei hosted by one of the largest pharmaceutical companies in the world, Novartis. The activities included attending speeches, presentations and lectures from leading persons, from various sectors such as policy, business and academia, concerning the development of biotechnology in Taiwan. The goal of the event was for the participants to understand biotechnology development from different perspectives. We were also involved in group activities including problem solving and presentations. Through listening to professionals in diverse areas and discussing with other participants, I was offered different

views of what was happening in biotechnology in Taiwan and I gained insights in the technical, policy, and business issues of development.

In spring 2007 I attended a three-day conference hosted by the Association for University Technology Managers (AUTM) in Tokyo. AUTM is an organization which brings together technology-transfer professionals, researchers and other intellectual property experts in order to learn more of issues related to university technology transfer. The topics that were discussed and presented during the conference included intellectual property regimes, university-industry collaboration, university entrepreneurship and industrial development. I also attended a number of press conferences arranged by private companies and research institutes, as well as policy organizations. These were related to the introduction of new discoveries, the release of new products, or information of open tenders.

In addition to the conferences, I attended a few seminars on the use of technical instruments involved in the production of biotechnology products. Arranged by GE Healthcare, these were aimed at training scientists and laboratory researchers on how to use the company's technical equipment. Although the discussions and presentations at the seminars were often too technical for me to understand, the meetings were still meaningful for me as they gave me a general picture of what kind of companies and organizations were attending and what activities they were using the equipment for.

Written sources

The written sources I have used have consisted of official documents, articles from academic journals and media coverage, industry reports, the internet, transcribed speeches and statistical material. The written sources have helped me to identify events and establish timelines, and have given me varied perspectives of the development processes studied. Sometimes they have functioned as a single source of information to describe a development process and give voices to resources. Other times they have helped to deepen and substantiate the picture given by interviewees. A categorization and the function of the written sources are given and described below.

Policy documents: In addition to the interviews made with policymakers, I have made extensive use of public documents from various policy and government-related

organizations[29]. I have considered these sources as important in order to understand and form the official view of policy. In comparison with statements made by policymakers in interviews, where it was sometimes unclear whether what was said was a personal opinion or a statement publicly supported by the organization, official documents offer no such ambiguities in representation. As they provide an official voice, these documents are the main sources used to represent the government policy in, for example, the development of the Taiwanese semiconductor and biotechnology industries.

A large amount of information was available in written documents, in the form of investment prospects, information pamphlets, white papers or yearbooks produced by the Ministry of Economic Affairs (MOEA), including its various sub-units such as the Biotechnology and Pharmaceutical Industries Program Office (BPIPO) or the Department of Industrial Technology (DoIT), among others. The websites of government and semi-public organizations and the content found there was another major source for official statements. A majority of the statistics used in this dissertation on the biotechnology industry were collected from government organizations (for a discussion of quantitative data, see below).

Articles from academic journals, historical accounts: Written accounts and analyses of development processes and events have been used as first-hand information to increase my knowledge of certain phenomena, but also to deepen the picture given by interviewees. The reason for not only relying on oral sources has been that for some events, especially in the semiconductor industry that happened over thirty years ago, it has been difficult to find persons involved and to schedule interviews. Hence I made the judgement that it would be easier and more beneficial to consult existing literature. The historical accounts have provided extensive development descriptions and analyses of the Taiwanese economy and industrial and technological policies from the 1950s onwards. There are also a large number of publications, in academic journals, aimed at describing the Taiwanese economic miracle and the growth and development of the semiconductor industry. The analyses made in the articles mostly discuss the role of the government and its related research institutes in the development process. As for biotechnology development (business and industrial) in Taiwan there are few development accounts and few publications in academic journals.

[29] Included in the category of government policy are also the semi-public research institutes, for example, DCB, NHRI, ITRI et cetera. The reason is that they derive a large proportion of their funding from the government and they often work closely with policymakers to create scientific and industrial policies. Hence they have been created by policy for a special purpose and the senior positions in these organizations are appointed by the government.

Newspaper articles, business magazines, industry reports: Industry reports offer up-to-date information of current development prospects and identify problems and business opportunities that are present in the industry. Similarly, newspaper coverage, although not made use of to any great extent, also provided the latest information on development projects and contemporary events. As a source, the material provided market insights and often gave me background information. Furthermore these sources provided me with quotes and were used to give (popular) opinions of development trends. They also gave me additional information to deepen and verify information and statements from both primary sources and secondary sources. The majority of these sources were found on the internet.

Statistical material/Quantitative data: Quantitative material has been helpful to explain or illustrate outcomes, results, and change over time. I used numerical figures to substantiate some of the information that was given by other written and oral sources. The quantitative indicators, such as sales figures or number of companies et cetera, given by interviewees were always double checked if possible.

The majority of the statistical material used has been compiled by government-related organizations, including the Industrial Economic Knowledge Center at ITRI, and Taiwan Institute of Economic Research to mention a few. Of course a caveat when using statistics is how these numbers have been compiled, which very much depends on the methodology applied by the researcher. In some cases I was somewhat cautious in using the figures as the methodology for reaching those numbers was usually not accounted for in a clear way. Overall this was not a large a problem, however, as the numbers have more or less been used with the purpose of conveying a certain opinion or trend. Furthermore, whenever I used quantitative data, consistency was a guiding principle. For instance, I would as far as possible use the same source and group of data in order for the numbers to be comparable.

CHAPTER 4
THE TAIWANESE SEMICONDUCTOR INDUSTRY

In the following chapters, the empirical study consisting of four parts is presented. The first part (chapter 4) relates to how an industry based on semiconductor development, production and use emerged in Taiwan including Taiwanese policy's interpretation of how the industry emerged. The second part (chapter 5) shows how this policy interpretation has been used as a role model for how to support and build a biotechnology industry in Taiwan. The third and fourth part (chapters 6 and 7) consists of two cases investigating how policy's support to an industrial structure in biotechnology has (and has not) resulted in development, production and use of new commercial solutions.

As was mentioned in the first chapter, the Taiwanese government has directed much attention and resources to create a biotechnology industry. In order to understand these policy endeavours, I will start with an overview of policy's main empirical source of inspiration, the Taiwanese semiconductor industry. Chapter 4 is divided into two sections. The first section (4.1) offers an empirical account of how development, production and use emerged in the Taiwanese semiconductor industry. In the second section (4.2), a portrayal is provided of how policymakers have interpreted the development process and subsequently made it into a role-model used to stimulate the emergence of other industries.

4.1 An empirical account of the emergence of the Taiwanese semiconductor industry

Taiwan has been considered one of the economic miracles of the twentieth century (World Bank, 1993; MOEA, 2005). The annual growth rate from 1952 to 1993 was 8.7 percent, an impressive number which few other countries have surpassed over such a long period of time (Chuang, 1999). In just a few decades, the Taiwanese economy went from being dependent on low-tech agricultural production to become a technological powerhouse and one of the leading semiconductor manufacturers in the world. How this was achieved has been studied extensively and often it is attributed to the government's active role in economic planning and coordination (Wade, 1990).

Today Taiwan is the twenty-fourth largest economy and has the fourth largest semiconductor industry in the world (TSIA, 2006; IMF, 2008). Based on the economic success of the industry, the government has lately been vigorously promoting a knowledge-based economy and aims to transform Taiwan into a *green silicon island*. With the hope of creating a second economic miracle, the semiconductor industry has played an important role as an inspiration and model to follow (Her, Internet). What now follows in this chapter is an empirical account of how development, production and use in the semiconductor field emerged in Taiwan. In the chronology below, some of the major events in the emergence of the Taiwanese semiconductor industry are outlined.

Table 4.1: Chronology: major events in the Taiwanese semiconductor industry

1961	The first foreign electronics companies, such as Philips and IBM, establish a presence in Taiwan.
1964	National Chiao Tung University establish the first semiconductor laboratory in Taiwan
1966	Texas Instruments establish the first semiconductor assembly operation in Taiwan.
1973	The Taiwanese government decides to develop a semiconductor industry.
	The first public research institute, Industrial Technology Research Institute (ITRI) is founded through the merger of three government laboratories in Hsinchu.
1974	The Electronics Research Service Organisation (ERSO), a sub-department of ITRI, aimed at developing semiconductor technology is founded.
1976	A technology transfer of a mature technology to ITRI from US semiconductor producer RCA Semiconductor and Materials.
1978	A special government expert committee created, known as the Science and Technology Advisory Group (STAG).
1980	Taiwan's first semiconductor company, United Microelectronics Company (UMC), a spinoff from ITRI, is founded.
	The Hsinchu Science Based Park is established.
	UMC is the first company to locate in the Hsinchu Science Based Park.
1986	The second spinoff from ITRI, Taiwan Semiconductor Manufacturing Company is founded.
	Semiconductor foundry as a business model is established with the emergence of TSMC.
1988	The Taiwanese semiconductor industry starts to grow rapidly.
2004	The Taiwanese semiconductor industry the fourth largest in the world.

The Taiwanese electronics industry – paving a way into semiconductors

The ambition of the Taiwanese government to make the transition into technology-intensive sectors formally appeared in the 1970s. The move was believed to be needs driven for reasons such as industrial development and international recognition (Chang et al., 1994). The Taiwanese government had however already started to pay more attention to science and technology in its policies in the 1960s according to Greene (2008). Prior to that, public policies had been aimed at measures which would build up a military capacity in Taiwan in order to launch an attack to retake mainland China. Initially, production on the island had been directed towards agriculture, but after the Kuomingtang[30] (KMT) assumed control over the former Japanese colony[31] in 1949 an import substitution policy was adopted. This stimulated the growth of new industrial sectors, such as plastics and textiles. In the 1960s, the Taiwanese leaders started to promote the export industry in order to increase national income and earn foreign currency as a result of reduced US financial aid.[32] The government policies encouraged the development of labour-intensive light industries (Wade, 1990; Chen, 1999).

By the 1970s the import substitution and export subsidy policies had turned the trade deficits into regular trade surpluses. The economy was growing rapidly, and with the strengthening of the textile, plastic, and electronics industries, the government's plan was to accumulate as much foreign reserve as quickly as possible. The momentum was however temporarily brought to halt due to competitive pressure from emerging neighbouring economies and political crisis as a result of China taking over Taiwan's mandate at the United Nations in 1971. The global oil crisis in 1973 also brought an economic downturn. These events forced the Taiwanese government to search for new avenues through which sustainable economic and political development could be created. To realize these goals it was believed that the focus had to shift from the labour-intensive consumer goods industry to technology intensive manufacturing industry (Wade, 1990; Chen, 1999; Hsu & Cheng, 2002). The industries that were targeted for export promotion to attract foreign currency and investments had been identified with the help of Stanford Research Institute (SRI) in the early 1960s (Interview, Michael Nystrom). As noted by Ernst (1997: p7): "SRI chose those product

[30] The Kuomintang was the first political party of the Republic of China. During the Second World War, the KMT was the ruling party in China, but after the war internal conflicts and the growing strength of Communist party led to the defeat of the KMT, which had to flee into exile. The KMT leader Chiang Kai Shek brought over to Taiwan a whole administration and an army in 1948; a total of 2 million people moved.
[31] Taiwan was a Japanese colony between 1895 and 1945
[32] In the 1950s it was financial aid from the United States that helped Chiang Kai Shek to maintain a large military force without overheating the weak economy.

groups where American companies had strong interests: certain petrochemical intermediates, plastic resins, synthetic fibres, transistor radios, electronic components, watches and clocks". To motivate foreign investments, an export processing zone was also established in Kaohsiung in Southern Taiwan in 1965[33]. As a result, increased amounts of investment by US, Japanese and European electronics companies started to flow in. The operations, taking advantage of the low-cost labour, were concentrated towards the manufacturing of electronics and electronic components (Mathews & Cho, 2000). The next section will describe the emergence of the Taiwanese electronics industry.

As mentioned, an active export promotion policy was implemented in the 1960s. A reason for this was the reduced financial aid from the US, which prompted the Taiwanese government to seek income and foreign currency through other means. Generous incentives were given to foreign companies willing to invest in Taiwan. The foreign direct investments came in the field of consumer electronics and the pioneers were IBM and Philips. IBM had set up operations in Taiwan in the late 1950s, and also established an affiliate producing core wires by the early 1960s. The business model was geared towards moving labour-intensive stages of final assembly to low cost countries. Similarly, Philips took advantage of low cost manufacturing by establishing a subsidiary in Taiwan in 1961, manufacturing TV sets, audio equipment and related components. Soon an inflow of Japanese direct investments came, the first was Matsushita that set up a majority owned joint venture in 1962. Up to the mid-1980s this venture was one of Matsushita's major production facilities in South East Asia. Sanyo followed in 1963, Hitachi in 1965, and Sony in 1967. By the 1970s, most of the leading Japanese electronic producers had established a presence in Taiwan or were engaged in labour intensive assembly with a growing share of output going to Japan or Japanese affiliates in Asia. American companies had also realized the benefits of being in Taiwan. For instance, in 1964 General Instruments directed production of transistor radios to Taiwan (Ernst, 1997; Mathews & Cho, 2000).

While several companies had set up subsidiaries, others acquired a direct stake in existing local companies. The latter strategy was for example used by Toshiba, which had in the 1950s acquired a 5 percent equity-share in Tatung Co. Taiwan's only integrated electronics company at the time. Initially, Tatung was only a distributor, selling various electronic products produced by Toshiba. In the 1960s the cooperation deepened and Tatung also received technology licenses from its Japanese partner, allowing the company to become

[33] The first in the world; various tax incentives were given to local as well as foreign companies interested in investing in the zone.

a supplier of key components, such as high-end compressors, picture tubes and LCDs. Other Japanese companies such as Fujitsu followed with a similar approach when it in 1973 established a joint venture with Tatung. The deal gave Tatung the rights to both sell and service Fujitsu computer systems and peripherals. These events eventually led to a number of joint ventures and OEM (Original Equipment Manufacturing) contracts with Taiwanese companies. Thus the investments made by foreign manufacturers of consumer electronics gave rise to a rapid growth in demand for electronic components produced in Taiwan. Although most of the high value-added key components were imported, both local production and capacity were increased (Ernst, 1997; Tu, 2001).

The foreign direct investments played an important catalytic role for the emergence of a Taiwanese electronics industry. For example, the Japanese companies offered intensive on-the-job training as well as developing close links with local suppliers that focused especially on the domestic market. Affiliates of Japanese electronic companies in Taiwan had considerable decision autonomy in areas such as salary levels, employment and work practices, as well as on how to organize production and procurement of components. A main reason for this autonomy was that the Taiwanese market could tolerate lower quality standards than the major overseas markets. A significant scale of local linkages was created by the foreign investments. Furthermore, the companies that invested provided the local employees and suppliers with education, knowledge and technology, although not advanced. Some of the employees also started new local companies. For instance General Instruments' Taiwanese affiliate itself gave rise, through former employees, to the founding of 11 local companies. In addition to being an incubator for local suppliers, foreign companies also established other facilities. Matsushita for instance created the Matsushita Electric Institute of Technology in 1981 with a work force of around 40 researchers (Ernst, 1997; Lin, 2003).

The events mentioned above preceded the growth of a domestic semiconductor industry. The first company to introduce semiconductor related business to Taiwan was General Instruments, who established a semiconductor assembly plant in Taiwan in 1967. Between 1969 and 1973, other multinational companies such as Philips, RCA and Texas Instruments followed suit and established their semiconductor assembly operations in Taiwan (Mathews & Cho, 2000). By contrast, the first semiconductor related research activities in Taiwan had local roots as discussed by Chang & Tsai (2000: p186): "The theory and technology of semiconductors was first systematically introduced in Taiwan when National Chiao Tung University started a course in 1960. The university built a semiconductor laboratory in 1964 that succeeded in manufacturing its first integrated circuit in 1965. National Chiao Tung

University then chose semiconductor technology as the main focus of its curriculum, with the aim of training more high-tech manpower". According to Chang & Tsai (2000), National Chiao Tung University later also cooperated with governmental units and provided a foundation for the semiconductor industry in terms of basic research and human resource development.

A government initiative to create a new industry

Foreign direct investment was a factor that contributed to the emergence of a Taiwanese electronics manufacturing industry. The largest export industry in Taiwan at the time was textiles, but the electronics sector was growing quickly. Although the manufacturing of electronics products brought income to the export sector, those activities were believed by Taiwanese policymakers to be isolated from the rest of the economy and to have little value in terms of industrial development. The reason expressed by Lin (2003) was that the foreign companies saw Taiwan only as a low cost manufacturing resource. Furthermore, there were no local companies conducting any technologically advanced R&D. However, the fast growth and the volume of applications possible, in for example consumer electronics, telecommunications and industrial electronics, made the electronics industry an attractive sector for Taiwanese policymakers to promote. With this ambition, the main issue became to find a key technology that would help the Taiwanese electronics industry to develop in the direction of technology-intensive products. Hence, expert advisors suggested that Taiwan should develop semiconductors, specifically integrated circuit design and manufacturing technology in order to stimulate innovation throughout the island's electronics industry. Chang et al. (1994: p163) provide the following explanation for why the Taiwanese government decided to concentrate on semiconductors:

> Since the integrated circuit was introduced in 1958, its small size, low power consumption, rapid operating speed, reliability, and low cost per electronic function have led to significant changes in all electronics products, including consumer electronics. If the IC industry were developed in Taiwan, a spillover effect would be generated for industries which use ICs. The IC was thus selected as the key technology to be developed.

Taiwanese companies had however no experience in making semiconductors. Beside the foreign manufacturers there were no local companies with experience or knowledge concerning semiconductor design or manufacturing. A task force, The Technology Advisory Committee (TAC), funded by the Ministry of Economic Affairs (MOEA) was therefore set up with the mission of investigating how to carry out a development strategy for the semiconductor industry. The TAC was formed by Y.S. Sun[34] (at the time the Minister of Economic Affairs) and P.W. Yuan, an engineer at RCA, in Princeton. The formation of TAC had been preceded by the belief that the key to a successful technological upgrading was to leverage the experience and knowledge of overseas Chinese engineers working in the US (Mathews, 1997). It was this group of highly skilled Chinese engineers, and academic scholars, working at various semiconductor companies and universities in the US that became the recruiting base for the TAC. Eventually the TAC also produced the guidelines concerning how to develop a semiconductor industry (Tung, 2000; Interview, Lee Chong Chou). The main areas of the strategy are highlighted below (Chang et al., 1994: p163):

1. TAC became responsible for the planning of the development. This was decided because there was no local experience in integrated circuit design and manufacturing available.
2. Since the gap between advanced semiconductor producing countries and Taiwan was very large, the main strategy to quickly develop an industrial base was through technology transfer.
3. The purpose of introducing semiconductor technology was to create an industrial base and to establish this kind of technology in Taiwan. The technology would have to be assimilated and developed. For this purpose a new research institute, ITRI was formed to reach the initial goals.
4. Over a period of 4 years, 410 million NTD (13 million USD) was to be invested by the government to purchase the manufacturing technology, product design and training personnel

[34] Sun was responsible for laying the foundations for Taiwan's technological upgrading. Both he and Yuan agreed that the electronics industry would be the key to Taiwan's transformation, and that semiconductors should be a key technology. Furthermore, they believed that the required knowledge needed to be leveraged from abroad.

The creation of a public research institute and technology acquisition

Who would take the lead in developing a new industry? The private sector companies, the majority of them being small or medium sized[35], were not technologically sophisticated enough. Neither did those companies place much emphasis on increasing R&D activities and investments (Liu, 2002). The few large companies, all involved in traditional industries, were reluctant to invest in new unproven industries (Mathews & Cho, 2000). Consequently it was believed by policymakers and experts that "no existing industry in Taiwan could lead the way in developing future high-tech industries for more than ten years" (Chang & Hsu, 1998: p350). In addition, the Taiwanese capital market was underdeveloped and financial institutions were conservative in lending out capital for risky ventures (Saxenian, 2000). Due to these circumstances, there was no other choice than for the government to assume the responsibility of being in the frontline in building up a semiconductor industry. In order to commence semiconductor related activities, the Ministry of Economic Affairs merged three government laboratories located in Hsinchu to form ITRI in 1973.[36] The government commissioned the newly founded research institute to carry out the introduction and assimilation of semiconductor technology. ITRI was thus the sole institution in Taiwan chartered to develop a semiconductor industry. With that purpose, ITRI established in 1974 the Electronic Research and Service Organization (ERSO)[37], a unit specifically concentrating on semiconductor technology (ITRI, Internet). The responsibility for planning and coordination was however still in the hands of the TAC. Since no domestic proprietary technology existed. TAC decided to acquire it from abroad (An, 2001). What technology would be suitable to license?

The first integrated circuits had already been developed in 1959[38], and by the 1970s a large number of integrated circuits with various features and technology platforms existed. In the mid 1970s the most advanced integrated circuit designs had a 3.0 micron bandwidth. After some initial enquiries however, no companies were interested in transferring cutting-edge technology to ERSO. The only technologies available for licensing were 7.0 micron chips. After lengthy discussions concerning the opportunities, the conclusion reached by the TAC was to obtain low power, high density technology that would provide submicron development

[35] According to Saxenian (2000), SMEs make up 95 percent of all companies in Taiwan. MOEA states that 90 percent of all Taiwanese companies in the 1950s were enterprises with 10 or fewer employees. In the 1960s the proportion of SMEs was 95 percent.
[36] Union Industrial Research Laboratories, Mining Research and Service Organization, and Metal Industrial Research Institute were donated to ITRI by the Ministry of Economic Affairs
[37] At the time the lab was known as Electronics Industrial Research Center, in 1979 the name ERSO was adopted.
[38] By Kirby, at Fairchild Semiconductor

potential. The main points in the discussions of the TAC were according to Chang et al., (1994: p164) as follows:

1. It would be very difficult to license an advanced technology. Either the companies that possessed that technology would not agree to a transfer or the price would be very high. It was believed by the TAC that it would be more feasible to license a mature technology with lower competitive advantage.
2. The 7.0 micron technology was mature, and thus also held several advantages for a country which had no prior experience in semiconductor manufacturing and development, including higher consistency, complete technical documents, many skilled technicians, and effectiveness in the operation of the equipment.
3. Products manufactured with 7.0 micron technology were already out on the market and feedback was available concerning process technologies, product development, design technology and marketing channels. Acquiring the 7.0 micron technology would therefore allow Taiwan to learn about all aspects of integrated circuit technology from R&D to commercialization.

The search for partners was conducted by ITRI which believed that American semiconductor companies were the ones most suitable to license technology from. Hence, over twenty requests to companies in the US were sent out and a handful of companies returned a proposal for a technology transfer. After the Taiwanese selection committee had visited the prospective companies, two were selected as potential partners, RCA Semiconductor and Materials (hereafter RCA) and company X. The cost for RCA's deal was twice as high as the one given by company X, but the terms of the company's proposal were better. RCA's proposal included technology, process design and manufacturing management skills for integrated circuit fabrication, whereas company X's proposal consisted of process design and design technology. However, another dimension that came into play was also that RCA could provide a year-long training for 35-40 ITRI engineers at its laboratories in the US. In contrast company X only suggested training for 3 months for 3-4 persons. Since it was believed by TAC that the success of the project would be reliant on the extensive training of human resources, the difference in the suggested training of Taiwanese engineers came to be the critical factor in the decision-making. RCA's proposal was considered as the better choice. Although the guiding principle had been to select the deal with the lowest price, the technology content and personnel training proposed by company X was believed not good

enough to achieve the goal of introducing semiconductor technology in Taiwan. The technology that was licensed to Taiwan was the so called Complementary Metal Oxide Semiconductors (CMOS), which originally was developed by RCA[39]. The technology corresponded to the goals of TAC to acquire a "low power, high density technology that would provide submicron development potential". Targeting this technology meant also that ITRI would not be competing directly with established manufacturers (Chang et al., 1994; Chen & Sewell, 1996; Hung et al., 2005).

Responsible for coordinating the technology transfer was ERSO. While the agreement with RCA was being negotiated talented young Taiwanese engineers were recruited and trained at ERSO for a period of time while waiting for the pending transfer. After the agreement with RCA had been finalized in 1976, 37 engineers were sent to different laboratories and plants in the US operated by the company for one year of technical training. Many of these engineers would later become the corporate leaders of Taiwanese semiconductor companies (Chang & Hsu, 1998; Interview, Chris Huang). The agreement with RCA included the transfer of a 7.0 micron CMOS process technology, product specifications, design and testing technology for a digital electronic watch. Assistance in building a semiconductor plant and training of personnel were also included in the licensing agreement. While the engineers were sent to the US for training, ERSO were setting up a 4 inch wafer pilot plant for semiconductor manufacturing back in Hsinchu, Taiwan. When the engineers returned in 1977 the plant was already operational for test runs. The same year the first integrated circuits were produced by the pilot plant. The standard of the product complied with what had been agreed in the licensing contract (Chang et al., 1994).

ITRI had accomplished the introduction of semiconductor technology to Taiwan. Of course Taiwan was still far from catching up with advanced nations but the main goal was to learn more about semiconductor technology, and to accumulate knowledge. For this goal, a pilot plant, with design, manufacturing and testing capabilities had been built, and was geared towards producing simple semiconductors. As noted, RCA had developed the first CMOS integrated circuits, but CMOS was at the time not a widespread technology. According to Mathews & Cho (2000) RCA was actually about to withdraw from the semiconductor industry and the licensing deal with ITRI was an opportunity to squeeze some last income from a mature technology. The 7.0 micron CMOS was mature, and far behind the worlds

[39] CMOS technology was developed at Fairchild Semiconductor in 1963. In 1968 the first CMOS based ICs were developed at RCA. At the time it was a low power but slow alternative to the standard NMOS (another technology which ITRI wanted to license but proved to be too expensive) and TTL technologies.

leading LSI 2.0 micron circuit designs, nonetheless for ERSO this was a way of gaining access to the world of semiconductors. In retrospect, the licensing of CMOS technology proved to be a wise choice. First of all ITRI did not have to directly compete with established producers on a global market. Second the market share of CMOS was relatively small at the end of the 1970s, but started to expand rapidly afterwards to become the most used technology in IC design today.[40] After RCA withdrew from the semiconductor industry in the early 1980s, ITRI also inherited the intellectual property portfolio from RCA that had been related to CMOS technology (Lu, 1998).

ERSO's semiconductor fabrication plant had been built under the guidance of RCA. After being able to produce integrated circuits in 1977, used in electronic watches, ERSO soon also started to produce experimental semiconductors by using its own designs. By 1979 ERSO were getting better yields from these integrated circuits than what the licensed technology had given. In the early 1980s ERSO could provide CMOS of 4.5 micron and in the mid 1980s of 1.0 micron (Mathews & Cho, 2000). In 1979 ERSO also established a customer relationship with a Honk Kong electronic watch producer that bought integrated circuits from the pilot plant. The order of 10000 integrated circuits was small and the owner of the Hong Kong firm was a former college classmate of the person responsible for running the pilot plant, Shih Ching Tay. This deal provided ERSO with an opportunity to interact with a user. (Tu et al., 2006) The total amount of capital invested from 1975 to 1979 was 410 million NTD dollars (roughly 12 million USD). It was a substantial sum to be invested by the Taiwanese government in a single technology, but compared to the research budgets of large semiconductor companies it was not a considerably large R&D budget. After the introduction of CMOS technology the government's commitment also increased. Between 1979 and 1983, 670 million NTD was to be invested. The goal that had been set up by ITRI was to upgrade the technology from 7.0 to 3.0 micron (Chang, Shih & Hsu, 1994).

In 1979 the Taiwanese semiconductor sector still only consisted of ERSO's plant and a handful of foreign assembly plants. Local companies were not interested in semiconductors, as it was considered a risky and unproven business. The technology which ERSO had acquired and continued to develop was still far behind the global standards, which were getting to below 2.0 micron bandwidth. In addition, there was no real infrastructure to support

[40] Originally a low-power but slow alternative to TTL, CMOS found early adopters in the watch industry and in other fields where battery life was more important than speed. Some twenty-five years later, CMOS has become the predominant technology in digital integrated circuits. This is essentially because area occupation, operating speed, energy efficiency and manufacturing costs have benefited and continue to benefit from the geometric downsizing that comes with every new generation of semiconductor manufacturing processes (CMOS, Internet).

high-tech development in Taiwan and the investments required to resolve this issue would have to be quite large (Chiang & Tsai, 2000).

Hsinchu Science Park and the first ITRI spinoff - UMC

The ambition of creating high-tech industries in Taiwan had strong support in policy circles. A person who came to play an important role for the high-tech development was former Minister of Economic Affairs, Li Kwoh Ting. He had taken an initiative for the creation of a permanent advisory body to the government in science and technology issues. The group that was established in 1978, headed by Li, was named the Science and Technology Advisory Group[41] (STAG) consisted mainly of overseas Chinese with technical backgrounds. Many of the advisers in STAG had worked in the US and experienced the growth of high-tech regions such as Route 128 and Silicon Valley. Based upon their experiences, STAG suggested that Taiwan needed a specialist infrastructure to support advanced industries such as semiconductors (Saxenian & Hsu, 2001; Yu, 2007; Interview, Lee Chong Chou). The ambition to set up a specialized infrastructure gained adherence in the Executive Yuan, and under the sponsorship of the National Science Council (NSC) a science park was to be established. The decision was however not well received in all political camps. Mathews & Cho (2000) point out that the efforts to set up a science park were met with considerable opposition and scepticism in the Taiwanese Cabinet. The NSC was nevertheless successful in securing land near Hsinchu, where both the ITRI campus and National Chiao Tung University were located. In 1978 210 hectares of land had been expropriated by the Hsinchu county government to create the new park and in 1980 the Hsinchu Science Park Administration was established (Hsinchu Science Park, Internet).

The establishment of Hsinchu Science Park was to facilitate the creation of a high-tech industry, but there where no local companies that could locate in the park. What existed were a few foreign subsidiaries that were involved in the downstream stage of packaging and testing semiconductor products. There was also ERSO which had set up a pilot plant manufacturing semiconductors, but other than that there were no local companies specifically involved in semiconductor development and production. Since no private Taiwanese companies were involved in Large Scale Integration (LSI) and semiconductor related R&D

[41] STAG remains the main science and technology advisory group to the government up to the present. Since 1979, together with the NSC it has also served as the main organ for science and technology policy.

activities, the ERSO management decided to create a company (Chang & Hsu 1998; Mathews 2000). It was believed by ERSO that the prospects of a Taiwanese semiconductor industry would be threatened if foreign companies would first establish subsidiaries (Liu et al., 2005). Hence, the pilot plant at ERSO was to be spun off, and form the foundation of a new company named United Microelectronics Company (hereafter UMC). The spin-off would mark an important milestone in the development of a semiconductor industry. ERSO was now ready to exploit commercial opportunities with the technology that had been acquired 3 years earlier (Chen & Sewell, 1996). The idea of a spin-off from ITRI was however novel, and there were difficulties with raising capital for a project of this kind. ITRI sought funding from both private and public sources, and in the end the majority of the capital was provided by the government (mainly by securing funds from state owned banks). A large stake was also taken by five large private companies (Saxenian, 2002).

ERSO not only spun off the pilot plant, there was also an extensive technical personnel transfer in which around 180 persons were transferred to the new company. In addition, the process technologies which had been modified and developed at ERSO were given to UMC, mainly a 5.0 micron CMOS process technology. Furthermore UMC received ten Application Specification Integrated Circuit (ASIC) products as well, including integrated circuits for calculators, melodies, timers and telephones. By 1982 the transfer process had been completed and the operations of the new company began the same year (Chang et al., 1994). UMC pursued a niche strategy by focusing on ASIC products that had been transferred from ERSO. The first customers had been inherited from ERSO, but the company also started to attract low end electronics manufacturers from Taiwan and Southeast Asia as customers. The strategy to concentrate on these customers meant that UMC was able to avoid direct confrontation with the large Japanese semiconductor companies which were concentrating on standard products such as memory. Focusing on a niche market turned out to work well, and in November 1982 UMC had reached break-even point (Liu et al., 2005).

Even with the ongoing spin-off of UMC and the ensuing reorganization, ERSO remained active with continued development of the licensed technology. By 1980 ERSO engineers had reduced the bandwidth of the process technology from 7.0 micron to 5.0 micron. This was further improved to 4.5 micron the year after. Although this could be seen as an achievement in itself for a new organization with little experience in semiconductor R&D, ERSO was not getting closer to catching up with the leading standards. At the time the world's top semiconductor manufacturers were producing products using Very Large Scale Integration (VLSI) technology of 2.0 micron bandwidth. It was clear that Taiwan was still far

behind the top countries such as the US and Japan in terms of technological levels (Mathews & Cho, 2000).

Thus, with the current rate of progress would it be possible for Taiwan to catch up with the advanced nations? The advisers at STAG believed that although ERSO was successful in introducing and assimilating the CMOS technology, Taiwan was still far behind the advanced semiconductor nations, and some argued that the gap was actually increasing. The STAG advisers strongly advised that Taiwan should set its target at achieving VLSI capacity of 1.0 micron standard or higher. This would bring the technology competence in Taiwan on par with the top companies in the world. ERSO strongly objected to STAG's advice and argued that Taiwan should be patient in its efforts to develop an industry, and not take on that much risk by directly try to challenge the large semiconductor companies. This could quickly jeopardize what had already been built up. Officials at the state departments such as the *Ministry of Finance* and the *Economic Council for Planning and Development* were also opposing the suggestion from STAG. These departments were more concerned with issues related to macro-economic stability and were not interested in promoting a single technology. STAG's suggestion to achieve VLSI capability was however supported by some high government officials, such as the president and the premier. Hence, in 1983 it was decided that the government would invest 2.9 billion NTD (roughly 85 million USD) to pursue the plan to achieve 1.0 micron VLSI capability by 1988 (Chang & Tsai, 2000; Mathews & Cho, 2000).

This was a very ambitious goal considering the then current state of the Taiwanese semiconductor sector and the small involvement of the private sector. As earlier, the government entrusted the VLSI project to ERSO. UMC had also tried to convince the government that it was capable of handling the task, but it was considered too risky to hand over such a mission to a newly started company. Thus the plan was that a VLSI plant would be set up at ERSO. But where would the VLSI technology come from? Instead of turning to another large company as before, ERSO signed an agreement with two Silicon Valley start-ups, Mosel and Vitelic, to develop VLSI semiconductor chips. Already by 1985 a bandwidth of 1.25 micron had been achieved at ERSO for the CMOS technology, and in 1986 CMOS memory chips of 1.0 micron were available. Taiwan now had the capability of designing 1.0 micron chips. There were however no fabrication facilities in the country to produce these semiconductor chips (Mathews, 1997; Mathews & Cho, 2000).

The growth of design capabilities and the emergence of TSMC

The results of the VLSI project were advanced design capabilities and "state of the art" technology in one of ERSO's special laboratories. Where was Taiwan heading from here, should the designs be licensed to third parties for fabrication? The problem with lack of fabrication capacity became more obvious with the growing number of semiconductor design companies in Taiwan. As mentioned earlier ITRI had started to transfer the capabilities and resources which had been built up, the first one being UMC. In 1982 ERSO had also spun off the first two independent Taiwanese semiconductor design houses, first *Syntek* and shortly thereafter *Holtek*. But if no private sector companies would willingly get involved in the semiconductor industry, ITRI would have to create an industry through spin-off companies (Mathews & Cho, 2000).

In addition to the VLSI laboratory, ERSO had in 1985 set up a Common Design Center for chip design companies to develop application products, which was mainly aimed at start-up companies (Liu et al., 2005). This encouraged several overseas Taiwanese from Silicon Valley to return to Taiwan and start their own companies or expand their business with the support of the Common Design Center (Chiang & Hsu, 1998; Mathews & Cho, 2000; Liu et al., 2005). The semiconductor design industry in Taiwan did not really take off, however, even though the technological levels had been raised and were approaching those of the advanced companies. A reason was not only that there were no customers, but also a lack of fabrication capabilities in Taiwan contributed to the situation (Chen & Sewell, 1996). UMC was the only semiconductor company in Taiwan with a fabrication plant prior to 1987 (An, 2001). ERSO also had some fabrication capacity since it had retained a part of the plant for continued research after the UMC spin-off. Nevertheless, none of these plants were intended for VLSI manufacturing, and as noted earlier the development was moving towards VLSI technology. This capability was believed to be necessary in order to catch up with the advanced semiconductor nations. So how would the products developed with VLSI technology be manufactured?

In 1985 Morris Chang had become the new president of ITRI. Chang, an overseas Chinese with a Ph.D. from Stanford University in engineering, had three decades of working experience in the semiconductor industry and prior to joining ITRI was head of the global operations department at Texas Instruments. In Chang's first week at ITRI he proposed a new spin-off from ERSO. He suggested that this spin-off should be focusing strictly on manufacturing chips, i.e. *semiconductor foundry*, for local and international customers based

on VLSI technology. The rationale for this was mainly based on two reasons. First, most of the top 20 semiconductor companies in the world did not have financial capital to quickly upgrade their fabrication facilities to VLSI-standard. Second, the growing Taiwanese semiconductor design sector needed fabrication plants to meet their production needs (Liu et al., 2005).

The idea was quite novel, since up to now the semiconductor companies had been vertically integrated, involved in both design and manufacturing. Although these two activities are separable, the companies with fabrication capabilities were also designing their own semiconductors in order to reduce the risk of having semiconductor designs copied. The new spin-off from ITRI would be the first company focusing strictly of foundry. The proposal to create a pure foundry company was accepted by the government, but it was not to be fully funded by the state; instead it was to have both public and industry support. This would be a way to push the private sector to participate in the semiconductor industry. The government gave ITRI the task to find a multinational company as a sponsor. The ambitions for the new company was to become a global semiconductor company, and in order to receive credibility, technology and a cross licensing portfolio it was believed that a venture with a leading semiconductor company would be best (Chang & Hsu, 1998; Mathews & Cho, 2000).

The possibility of creating a large scale VLSI semiconductor business through financial support from the government and combined with engagement from an international semiconductor user, appeared an attractive solution. Interest was shown from four multinational companies: Texas Instruments, Intel, Philips, and Matsushita (Mathews & Cho, 2000). All of these companies, with the exception of Intel, already had prior production activities in Taiwan. Philips was the pioneer, starting production in Taiwan when the company established its production of TV sets, audio equipment and related components in 1961. In 1962 Matsushita established a production facility in Taiwan, to be followed by among others RCA and Texas Instruments. After the Taiwanese government had negotiated with all four companies, Philips proved to be the only serious candidate. In 1986 it was announced that the Taiwanese government and Philips would be the largest shareholders of the new company, Taiwan Semiconductor Manufacturing Company (TSMC)[42], and the company was established the year after (Chen & Sewell, 1996). ITRI provided the technical personnel, around 150 persons, of which most had been involved in the VLSI project. ERSO

[42] According to Saghafi & Davidson (1989) 10 billion NTD was raised. Philips became the largest private shareholder with 27.5 percent of the equity. The largest shareholder was the Taiwanese government, with 48.3 percent of the equity.

also spun off its 6 inch VLSI manufacturing plant that became TSMC's first fabrication facility. With this TSMC became the first dedicated foundry in the world, and pioneered a concept which became a central element of the semiconductor supply chain. Since Philips production activities in Taiwan already included semiconductor assembly operations, the step to an engagement in semiconductor foundry was already locally established (Saghafi & Davidson, 1989).

Through Philips' engagement, TSMC not only received a financier but also a large, skilled and demanding customer. In the technology area, Philips agreed to transfer 2.0 and 1.5 micron process technology to produce VLSI devices. For more advanced technologies Philips, would be paid royalty fees. The condition for the deal was that the new company would not become a competitor to Philips own products in Taiwan. The initial technology inputs supplied by Philips accounted for 80 percent of TSMC's original capability. Philips transferred its portfolio of cross licenses to TSMC to avoid the company being accused of infringing intellectual property rights of other semiconductor companies, something which had happened to several upcoming Korean semiconductor companies. In addition, Philips also supported TSMC with product and process know-how, but more importantly what was gained was legitimacy for the new company. As a result of the extensive support, TSMC experienced strong growth and was successful in upgrading its technology to world standards in a short period of time. Until the end of the 1980s TSMC had to rely on the support from Philips in order to be able to produce advanced integrated circuits. However, at the end of the 1980s both the customer base and the knowledge of making advanced semiconductors had grown so much that TSMC was able to design 0.8 micron semiconductors without any technical support from Philips. In the early 1990s, a decade after the operation started, TSMC's annual sales surpassed 1 billion USD, and the production activities included design and manufacturing of semiconductor chips (Mathews & Cho, 2000).

A growing semiconductor industry

As discussed earlier, by the time the government decided to promote semiconductors many foreign electronics companies had a steady presence in Taiwan. Philips had already been involved in Taiwan since the early 1960s when the company had set up a transistor and television tube factory, which today is the largest of its kind in the world and the main supplier of tubes to the Philips group. The company's commitment came to grow stronger

over the years. Hence, when the Taiwanese government searched for a partner to form TSMC, Philips was a potential sponsor. The reasons that Philips turned out to be the only serious candidate was not only because the company had the financial and technical resources but equally important was its long term dedication to Taiwan. It must be taken into consideration that TSMC was an unproven business idea and the burden of proof was on ITRI. The other companies, Texas Instruments and Intel were just not convinced of TSMC's potential, but for Philips the incentive to invest was the opportunity to gain a stronger foothold in the emerging Taiwanese market (Chang & Tsai, 2000; Mathews & Cho, 2000).

The development of TSMC functioned as a catalyst for the continued start-up of new semiconductor companies[43] in the Hsinchu region. Around TSMC and its interaction with customers such as Intel and Texas Instruments, a structure of related companies started to emerge. ITRI had also continued to run its R&D operations, and fuelled by its proven spin-off strategy, projects became companies as soon as technologies were considered ready for commercialization. The research institute maintained a liberal view on employees' ambitions to create new companies, direct as well as indirectly[44], and this benefited the enlargement of the semiconductor industry. With the growing opportunities, Taiwanese private capital was starting to flow into the semiconductor industry in larger amounts (Chang & Hsu, 1998).

UMC, the only other company in Taiwan at the end of the 1980s with fabrication capabilities, had already been listed on the Taiwan Stock Exchange in 1985. But although the company was profitable it was lagging behind TSMC in technological sophistication. For example, in 1987 when TSMC's technological capabilities were almost similar to the world leading producers, i.e. close to 1.0 micron, UMC only had 3.5 micron process technology. Furthermore, while TSMC was attracting large multinational companies as customers, UMC was serving mostly "small" customers (Chang & Hsu, 1998). However this did not mean that UMC was unsuccessful, the CMOS technology which the company inherited from ITRI was also becoming a standard technology used in producing integrated circuits. Initially ITRI had chosen to license a mature CMOS technology from RCA because the more advanced technological solution could not be afforded. Although CMOS based integrated circuits were a somewhat slower alternative to some more advanced solutions, it was also less power consuming. This meant that CMOS became an attractive solution for products where low power consumption was of greater importance than speed, for example in the watch industry.

[43] E.g. Destiny Technology Corp., Realtek, Weltrend, Sunplus, ICSI, Eltron et cetera.
[44] This high mobility of labour was also a major contribution to the successful development, according to Saxenian (2001).

Since the CMOS technology was considered by the dominating US and Japanese semiconductor companies as obsolescent, it became a niche product which UMC later became one of the few to supply. About two decades after ERSO started the development and production of CMOS technology it had emerged to become one of the predominant standards in integrated circuits. (Mathews & Cho, 2000) It was a combination of CMOS features, for example the geometric downsizing, the development of operating speed together with energy efficiency, and the low manufacturing costs that made CMOS a dominant standard in semiconductors (CMOS, Internet).

The two ITRI spin-offs followed different business models, but were nonetheless important as examples of how Taiwanese companies could succeed in the semiconductor business (Liu et al., 2005). TSMC and UMC had proven to be triumphant cases which encouraged private sector and non-public investors to participate in an industry which had earlier been dominated by government organizations. The development progressed quickly, and by the early 1990s Taiwanese companies had similar technology levels to those of the advanced global semiconductor manufacturers (Chang & Hsu, 1998; Hsu & Cheng, 2002).

Today the semiconductor industry is considered an icon of success in Taiwan. At the end of 2005, Taiwan Semiconductor Industry Association (TSIA) estimated that 60 percent of worldwide semiconductor foundry, package and testing revenues were generated by Taiwanese semiconductor companies. For worldwide revenue in semiconductor design as well as dynamic random access memory, Taiwanese companies held around 25 percent. The total economic value generated by Taiwan's semiconductor industry totalled 1118 billion NTD (roughly 33 billion USD) at the end of 2005. In the same year, the Taiwanese semiconductor industry consisted of 268 semiconductor design houses, 8 wafer suppliers, 4 mask makers, 13 fabrication companies (fabs), 33 packaging houses, 35 testing houses, 15 substrate suppliers, and 19 chemicals suppliers (TSIA, 2006). In Table 4.2 below the financial results of the industry for 2006 are summarized:

Table 4.2: Taiwanese semiconductor industry (2006)

Area	Revenue
IC Fabless	285
IC Fabrication	587.4
Foundry	373.5
IC Packaging	178
Domestic Packaging	149
IC Testing	67.5
Total	1117.9 Billion NTD

Source: (TSIA, 2007)

Summary

The story of the Taiwanese semiconductor industry is both an interesting and impressive example of industrial development. Some of the major actors that were contributing to the development mentioned in this chapter have been policy actors, foreign manufacturers, public research institutes and local industry. These actors are related to the development of three types of resource structures: a structure developing semiconductor technology; a producing structure, and a (business) using structure. Some major events which contributed to the development and emergence of these structures in the Taiwanese semiconductor industry were as discussed in this chapter: (a) the use of a mature technology which had already established connections to both producing and user interfaces; (b) the important role of foreign companies in teaching Taiwanese companies how to become suppliers, and also themselves becoming users; (c) the important role of policy in connecting the different structures. In the next section (4.2), an account on how the Taiwanese semiconductor industry emerged will be given from the perspective of Taiwanese policy.

4.2 Taiwanese policymakers' interpretation of the development of the Taiwanese semiconductor industry

The emergence of the Taiwanese semiconductor industry is without a doubt impressive. It is easy to understand that the emergence of such a dynamic science related high-tech industry attracts special attention. In the previous section I provided an empirical account of how three types of structures, developing, producing and using, emerged in the semiconductor sector in Taiwan. In this part it will be described how the emergence of a Taiwanese semiconductor industry has been interpreted by policy and become an influence to the Taiwanese government on how to create new science-based industries.

Just as Silicon Valley[45] has become a world-renowned role-model for how regional development should be organized, the tale of Taiwanese semiconductor success has become a reference for Taiwanese policymakers concerning how industrial development can be created. The quote below is an example of a widespread interpretation expressed by Taiwanese policymakers:

> The semiconductor industry was a creation of government policies. To take a few examples, it was our government that identified semiconductor technology as Taiwan's chance to catch up with developed countries. There was no semiconductor industry when ITRI started its operations in the 1970s and basically everything was developed from nothing. It was the government that created ITRI which since then has been a very important part of the infrastructure to build up a semiconductor industry. The government also decided to set up a science park where the industry could be located. (Interview, Lee Chong Chou)

This view is not only shared among policymakers but also by academic scholars and practitioners who have offered analyses of the factors behind the impressive growth. The development of the Taiwanese semiconductor industry is often referred to as a textbook example of how a government successfully engaged in the development, production and commercialization of semiconductor technology (see Chang, Shih & Hsu 1994; Mathews,

[45] "The rise of Silicon Valley has garnered worldwide attention because it seemed to offer the possibility that a region with no prior industrial history could make a direct leap to a leading-edge industrial economy, given the right set of circumstances, without the time and effort required to pass through any intermediate stages of development. Here was "cowboy capitalism" in its most raw and dynamic form. The idea that so much growth could occur in so short a time within such a small geographic area sent planning bodies and government agencies from Albuquerque to Zimbabwe scrambling to "grow the next Silicon Valley" in their own backyard" (Sturgeon, 2000:p15).

1997). As Liu (1993: p299) advocates, the case of the Taiwanese semiconductor model also sets a formidable example of how a smaller country with little prior technology background can catch up with more advanced countries through policy guidance:

> The success of Taiwan's economic development over the past 40 years is generally regarded as a premier model for developing countries […] the development of Taiwan's semiconductor industry can provide some lessons for those countries that want to speed up the pace of modernization and shorten the lag behind industry leaders.

The "semiconductor recipe"

What then, were the major features that led to the extraordinary development of the semiconductor industry in Taiwan? Taiwanese commentators such as Liu (1993); Tung (2001); Chang & Tsai (2000) among many others suggest that the Taiwanese model for high-tech development was based on the direct guidance and coordination from the government. In the words of Mathews (1997: p27), it is described as follows:

> Development at Hsinchu in Taiwan has been achieved as a deliberate matter of public policy. It was not a development so much as a creation. An institutional framework has been established with the conscious intention of facilitating the leveraging of advanced technologies from around the world and accelerating the uptake and mastering of these technologies by Taiwanese firms.

The role which the Taiwanese government undertook in guiding the development has been extensively analyzed. For example Chang, Shih[46] & Hsu (1994: pp161-162) argue that:

> The most critical factor is the competitive power of technology. Therefore, if a country wishes to overcome the limitations of its natural resources, or if the country's decision makers wish to change or upgrade the structure or level of existing industries, how to select suitable industries as the targets for development and how to effectively acquire competitive technology to develop these industries are important topics. […] Taiwan's IC industry was formed through the following process: IC technology strategically selected by the government, was introduced from RCA of the USA by the Industrial Technology

[46] Shih Chin-Tay was the director of ERSO during the 1970s and later became president of ITRI.

Research Institute (ITRI) and then transferred to the industrial sector after being assimilated and improved.

The role of the government has also been discussed by Liu (1993: p299), arguing that: "in a developing country without large enterprises, the government must play an active role in developing an emergent high-tech industry". In Table 4.3 below, the role of the government is outlined in four different stages of the development of the semiconductor industry:

Table 4.3: Government's role in the development of a semiconductor industry

Stages of development	*Embryonic (1966-1976)*	*Technology acquisition (1976 -1979)*	*Technology build-up and diffusion (1979-1988)*	*Self-supportive (1988-)*
Government Policy	Export promotion	Technology acquisition from abroad	In-house development, technology diffusion	Cooperative research, research consortia
Technological Milestone	No R&D or production	7 micron	1 micron	Sub-micron
Industry structure	Foreign companies (only involved in assembly and did not contribute to development)	ITRI and a pilot plant	Emergence of domestic companies in manufacturing and design	Many firms, more complete infrastructure, international competitiveness

Source: (Liu, 1993)

In this development scenario, Liu (1993) identifies three major policies which the Taiwanese government drafted as the factors to success: 1) technology acquisition; 2) in-house pioneer research, technology transfer and; 3) infrastructure build-up. Below is a more detailed description of the content of these policies and the role of the government, as it is understood from a policy perspective with regard to the development of the semiconductor industry.

Technology acquisition: As discussed by Chang, Shih & Hsu (1994), it was the Taiwanese government that took the initiative, planned and guided the acquisition and implementation of the technology. The reasons according to Hsu (2005: p1318) were that: "Taiwan's economy was generally comprised of small family enterprises. As a result, equipment and capacity in universities for basic research were weak, and most enterprises did not have any concept of R&D or R&D investment". The foreign companies that were present were also understood to

not contribute to the development of a high-tech industry (Liu, 1993). Thus the knowledge and technologies to create a high-tech industry were not available domestically and had to be acquired from abroad. The government chose semiconductor technology as the target in order to develop a high-tech industry (Chang, Shih & Hsu, 1994). Since Taiwanese companies did not have the capacity or the interest in developing semiconductor technologies, a public research institute (ITRI) was formed by the initiative of the government. ITRI obtained the directive to acquire technology from a foreign company. The funding for this project came entirely from the government. Since the private sector was unwilling to undertake any risk in a new field with no apparent economic value at first, it was necessary that the public sector took activities that no companies wanted to perform (Mathews & Cho, 2000; Interview, Kuo Chang Tang).

In-house pioneer research, technology transfer: Following the acquisition of the technology, the goal was to learn the production processes, followed by in-house development of the technology. This assignment was solely given to ITRI by the government, as Chang, Shih & Hsu (1994: p165) describe: "In order to establish technologies introduced from advanced countries into Taiwan and to develop high-technology industries, the strategy adopted by Taiwan was that ITRI was responsible for the work of introducing these technologies and then transferring them to industry after assimilation". Thus technology acquisition and in-house R&D were all committed by the public sector, and the government gave a public research institute the responsibility to lead the way in industrial high-tech development (Hsu, 2005).

After the (foreign) technology was acquired and developed to an acceptable level to be commercialized, a way to diffuse the results was needed. *Technology transfer* from ITRI through either spin-off companies from the research institute or directly by local companies became the mechanism to create a domestic industry. Since there were no domestic companies initially that were able to absorb and commercialize the technology, spin-offs became the common avenue for technology transfers to form an industry. These spin-offs would, following the transfer, continue to receive government support and funding (Liu, 1993).

Infrastructure build-up: For nurturing a nascent semiconductor industry, a *specialized infrastructure* was needed in Taiwan and, as a part of the government's development program *Hsinchu Science Park* was established in 1979.[47] Companies that would locate in the science park were granted preferential loans, tax reduction, administration services and other incentives (Chang, Shih & Hsu, 1994). The science park was intended to provide newly founded companies with a chance to collaborate with research institutes. The Hsinchu Science Park, also known as Taiwan's Silicon Valley, is described as follows by Liu (1993: p306):

> With its proximity to ITRI and two well-known technology-oriented universities (National Ching Hwa University and National Chiao Tung University), HSIP created an appropriate intellectual climate for R&D, and provided a ready supply of researchers and a focus for cooperative research. It also has very good infrastructure and back-up services. The Hsinchu Science-Based Industrial Park administration insists that companies within HSIP spend a certain proportion of their revenues on R&D, and that a minimum percentage of workers must be scientists and engineers.

To sum up, the view which has been outlined is that government played a central role in the development of the semiconductor industry, all the way from providing and developing technology to transferring it to the industry (Hsu, 1993; Chang, Shih & Hsu, 1994). Before the government actively started to promote the field, there was no industry. In order to overcome "market failures" at the various stages in the formation process of the industry, the government established research institutes to perform activities that no companies wanted to do (Tung, 2001; Hsu, 2005). Furthermore, an infrastructure consisting of a science park, investment incentives, et cetera were provided by the government to encourage private participation in the industry (Liu, 1993). In the next section I will relate this interpretation of the semiconductor development, i.e. the "semiconductor recipe", to contemporary government policies and formulations in developing new industries.

[47] The Hsinchu Science Park is often referred to as a "public sector version" of Silicon Valley(see e.g. Mathews 1997) and hosts the majority of the Taiwanese semiconductor companies.

Contemporary Taiwanese government policies concerning industrial development – Innovation and coordination

The interpretation that was painted above is strongly supported by Taiwanese policymakers. For example, in 2002 Huang Wen Hsiung Vice Chairman of the National Science Council pointed out in a speech that the Taiwanese economic development is the result of "the pragmatic and forward-looking development strategies formulated by the government at each stage of national development" (Huang Wen Hsiung, Internet). With this understanding, the semiconductor recipe has clearly influenced contemporary Taiwanese policymaking. The government has employed a similar template, formally known as the *Technology Development Program*, when planning the development of new industries in the new millennium. For instance, the industrial policies fashioned by the *Ministry of Economic Affairs* (MOEA) are executed by a number of sub-departments, and the *Department of Industrial Technology* (DoIT) is one the executive branches. An important aim of the DoIT is to identify and promote new technological areas (Ministry of Economic Affairs, Internet). Through the department's Technology Development Program (TDP) the major objectives have been to coordinate various sectors and create industrial innovation as exemplified in the quote below:

> The Technology Development Programs (TDP) have been a long-running initiative of the DoIT aimed at pooling the research resources from research institutes, the industry and academia to maximize their effectiveness. [This is done through three programmes] 1. Funding programs for Research Institutes support pioneering innovations, establish technological leadership and self-sufficiency, and realize industrial upgrades. 2. Funding programs for Private Sectors focus on assisting the private-sector with developing their own research capability to realize the objective of technology dispersion and industry upgrade. 3. Funding programs for Academia offer funding to research new innovative technologies and build up industrial technology innovation centers in order to promote the development of emerging high-technology industries. (Department of Industrial Technology (5), Internet)

In order to create industrial innovation Taiwanese policy identifies what technologies the industry needs and should concentrate on. Furthermore, it is decided by policy how the technologies are to be developed by research institutes, and also through which medium those

technologies should be transferred and used by the industry. These policy guidelines are very similar to the ones the Taiwanese government implemented, and identified in retrospect, for the semiconductor industry. As is mentioned on the DoIT website, the origin of the government's *Technology Development Program* and the related strategies also go back to the 1970s when ITRI and the semiconductor industry were founded. In this model it is the research institutes that are the core of the industrial development system (Department of Industrial Technology (6), Internet). The program began formally in 1979, as the MOEA describes:

> MOEA began setting aside budgets to commission research institutions to take part in industrial technology research and development projects. The technology R&D work headed by the government has been oriented around advanced technologies, including applied research and development and the development of key technologies and components (Department of Industrial Technology (4), Internet).

In later years the Taiwanese government has also paid more attention to development organizations which perform basic research and a producing structure consisting of companies in the private sphere. (MOEA, 2005) This has resulted in technology development programs (TDP) specifically aimed for the academic and the industrial sectors (Department of Industrial Technology (3), Internet). For the Academic TDP some of the objectives have been to increase patents and include universities in the mission of industrial development.

> Over the past five years, the R&D Center of Excellence program has successfully promoted the formation of 54 thematic innovative and perspective industrial technology R&D centers from 21 universities, and 7 cooperative education alliances. This naturally attracts universities' attention to voluntarily consider the needs of industrial development and the industrial benefits of patent application and commercialization. To date, the achievements include: 1,445 patents filed, 327 patents granted, 265 cases of technological transfer (valued NTD 119.01 million), and 338 derivative assignments (valued approx. NTD 258.82 million) (Department of Industrial Technology (7), Internet).

At the down-stream level, the development program is described by the Taiwanese government as having the following focus:

> Industrial Technology Development Program was the first one to provide direct funding for enterprises to participate in industrial technology research. By the end of 2007, 424 projects had been carried out by 691 businesses, with nearly 15,000 researchers. Government grants was about NTD11.43 billion, and businesses investing facilitated to NTD 29.86 billon in return. On average, each NT dollar spent by the government through Industrial Technology Development Program resulted in 10.39 NT dollars of industrial output. […] Two types of innovation center programs were devised; with the first being the Multinational Innovative R&D Centers in Taiwan Program aims at attracting international R&D resources to Taiwan. The other was the Industrial Technology Innovation Center Program aims at establishing R&D centers that will help Taiwanese industries become technology R&D oriented. By December 2008 the two programs have helped establish 100 domestic enterprise R&D centers while also persuading 30 multinational enterprises to set up 39 R&D centers in Taiwan. These will carry out over 550 collaborative research projects in Taiwan and generate over NTD 37 billion in research spending (Department of Industrial Technology (8), Internet).

A new development discourse - From imitation to science based innovation

As has been described, industrial development in Taiwan is focused around three different governmental programs which guide industrial development, i.e. the technology development programs for research institutes, the academic sector, and industry. The first of these, which draws its inspiration from the semiconductor industry focuses on the research institutes, which acquire and source technologies from abroad and domestically to develop in-house and thereafter transfer to industry. The other two programs are aimed at local companies and universities respectively, to establish innovative technologies and domestic R&D capabilities.

Compared to earlier a large change in Taiwanese policymaking is the focus on innovation as the foundation of industrial development. In this context local universities and companies have received a more prominent role in the government plans to achieve this purpose. Moreover, in the knowledge-based economy, industrial innovation is supposed to start from basic and applied scientific research. The innovation strategy has been distinctively profound in Taiwanese industrial policy over the last decade. However, the public policies that emerged in the 1970s and 1980s aimed at developing a semiconductor industry were based on acquiring and adapting foreign technologies for the research institutes to create a local industry. In the 1990s, the industrial policy discourse had changed to favour a more

innovation driven industrial development (Wong, 2002; Eriksson, 2005; Interview, Jack Chang). For instance as Huang Wen Hsiung, Vice Chairman National Science Council Executive Yuan commented in a speech in 2002:

> In keeping with the global trend towards technological and industrial development, the government will forge ahead with the implementation of the industrial development strategies discussed above. Taiwan will be transformed from a production based Taiwan to a knowledge based Taiwan (Huang Wen Hsiung, Internet).

The view which has prevailed in contemporary Taiwanese policymaking is that Taiwan needs to create its own technologies rather than to imitate, as was earlier done. This ambition is described by Wong (Internet):

> In the past, Taiwanese firms were able to adroitly borrow technology and, in turn, produce better quality goods faster and more cost-effectively. In post-industrial or post-manufacturing sectors such as biotech, businesses can no longer borrow technology, but must instead create technology.

A larger vision of this transition was described in the Taiwanese government's *Plan for National Development in the New Century* (2001-2004) where the attention was centered on developing knowledge-intensive fields to stimulate the economy:

> As the experience of the advanced industrial countries demonstrates, knowledge has become the driving force behind manufacturing excellence and economic dynamism. Investments in knowledge must be large enough to bring into play cross synergies and scale economies, and must focus not only on the development of new knowledge but also its productive application. […] The steady accumulation of knowledge and constant innovation in science and technology will boost manufacturing productivity, stabilize the economy, and speed Taiwan's emergence as a global operations center for new, traditional, and high-tech industries (CEDP, 2006: p15).

With this ambition, the main development strategies for industrial revival were in the *Plan for National Development in the New Century* to:

> Strengthen domestic research and development to reap the benefits of innovation and technological progress. At the same time, acquire cutting edge technology from the advanced industrial countries and, when appropriate, attempt to benefit from externalities associated with world-class research and development conducted in those countries. […] Upgrade the infrastructure and the legal and administrative framework relating to science, technological, medical care, and the environment, creating conditions conducive to the accumulation and dissemination of new knowledge. […] Develop a nationwide system for the promotion of technical knowledge and innovation (CEPD, 2006: pp17-18).

As understood, the revitalization of the economy is dependent on the ability to develop, produce and diffuse resources based on new knowledge to the industry. To achieve a sustainable development and economic growth the government has clearly stated that there is a need to:

> Establish a mechanism for the promotion of innovation, job creation, and the development of emerging industries. […] Strengthen industrial innovation and R&D, upgrade industrial technology, and accelerate the pace of industrial restructuring. (CEPD, 2006: p27)

In order to achieve these goals and economic development, the Taiwanese government promotes an innovation system where three different structures (development, production, and use) interact:

> There are over 150 universities and colleges in Taiwan providing the human resources needed for industrial development. In addition, several research institutes were established to develop technologies needed for industrial development. To further stimulate industrial development, the government also formulated various policies and initiatives to build an industrial innovation system. These include the Technology Development Programs, research organizations with collaboration among industry, universities and research institutes, R&D parks, tax exemptions, venture capital systems, and industry clusters. The establishment of such a collaboration system has stimulated rapid communication of knowledge among these sectors. This has become the main driving force behind local industrial development and, in turn, will be the advantage for international R&D investment in Taiwan (Department of Industrial Technology (1), Internet).

Summary

In section 4.1 the emergence of the Taiwanese semiconductor industry was portrayed. It showed how semiconductor technology was developed, a producing structure was built up, and how use was created. There was not any single mechanism triggering the development, but one important factor to the growth was the ability of the different settings to take advantage of what existed in the other structures. For instance, the development of semiconductors in Taiwan was not based on what was traditionally considered as desirable in research, that is to say cutting-edge discoveries, but was driven by research on a mature solution that had already been implemented in existing producing and using structures. The development of a producing structure was performed in close relation to the support of a using structure and their specifications. In these processes extending beyond national, organizational and technological borders, a large numbers of actors, representing policy, the private sector and academia participated.

In section 4.2 a development model formulated by Taiwanese policy based on the development of the semiconductor industry was outlined. The main components of the model were as follow:

1. Government identifies market needs and the necessary technology needed to create an industry.
2. Research institutes source/acquire technologies from abroad and develop them in-house
3. The technologies from research institutes are licensed to existing companies or spin-off companies are created from the development projects.
4. Government provides support by building up infrastructure, providing investment incentives etc.

Universities, and local companies as well as the foreign ones were viewed by the Taiwanese government as less influential in the development of the semiconductor industry. Instead it was the government and its affiliated research institutions with semiconductor technologies acquired from abroad that had a dominant role in the creation of the industry. This model has in retrospect become a main influence in developing new industries, and it forms the foundation of the MOEA's technology development program. In recent years this template has also been amended with a government preference for the Taiwanese industry to be more

innovative and to develop its own technologies, rather than imitating or acquiring existing technical solutions from abroad. The government rhetoric and support for this strategy has been strongly influenced by research on innovation systems.

The ambition to develop a knowledge economy and innovations is not particularly different from what other governments in the developed world have expressed. These ideas have been strongly promoted by the OECD for the past two decades. In this view, a shift to knowledge intensive sectors is considered as the next step in economic development. Consequently, advanced economies have been setting an agenda moving towards establishing industries related to these areas. In order for Taiwan to achieve this, Taiwanese policymakers have viewed the semiconductor industry as an inspiration concerning how policy can actively create further development, i.e. to take the next economic leap. The influences from the semiconductor industry interwoven in a discourse on the new knowledge based development can be clearly observed in government policies directing the development of new science based high-tech industries, as will be demonstrated in the next chapter which concerns the emergence of a biotechnology industry.

CHAPTER 5
THE TAIWANESE BIOTECHNOLOGY INDUSTRY

In the previous chapter (4.1) an empirical account of the emergence of the Taiwanese semiconductor industry was presented. What was portrayed was a process of development, production and use of semiconductors extending over time beyond the borders of companies and countries. Involved were representatives of established semiconductor businesses, foreign universities, and research institutes, as well as Taiwanese policy organizations, local companies and research institutes. This account was followed by Taiwanese policy's interpretation of how the industry emerged (4.2). The policy interpretation saw the government as an actor that played the main role in the planning and creation of the semiconductor industry through promoting development and production of semiconductors in a linear fashion.

Both descriptions depict the emergence of the Taiwanese semiconductor industry as an impressive journey. The latter is also heavily used in the government rhetoric to create new industries. With the Taiwanese semiconductor industry becoming a role model to follow when developing new industrie*s*, the Taiwanese government has come to implement a more top down control of science and technology planning. As expressed in a policy report: "the formation of Taiwan's S&T policies previously emphasized the bottom-up assessment of units' needs, and neglected the top-down consideration of overall strategies" (National Science Council, 2005: p6). The "semiconductor recipe" has come to offer this set of overall strategies in creating innovation and developing new industries.

But how does such an attempt look like? In the next chapter we will consider how Taiwanese policy has used a template similar to the "semiconductor recipe" (described in 4.2) to stimulate the creation of a new industry, namely biotechnology. The chapter includes a description of emergence of industrial activities and how policy has aimed at promoting upstream, midstream and downstream sectors. It is concluded with a portrayal of how the emergence of a biotechnology industry has been perceived by Taiwanese policy and various biotechnology commentators.

5.1 Biotechnology – A field of research and business surrounded by high expectations

By taking a glance at contemporary policy plans it is evident that innovation has become an increasingly important component in planning economic development on both regional and national levels. Policy organizations such as the OECD or the UN have actively supported the view of innovation as a major factor of economic growth (Eklund, 2007). As a testament to the extensive adoption of this idea, there are a large number of examples where governments all over the world are trying to create innovative business-regions and industries based on knowledge-intensive fields[48]. One area that has received special attention for these intended purposes is biotechnology (Waluszewski, 2004b). But what is biotechnology, and why all the hype surrounding this industry?

The biotechnology field consists of a large variety of technologies which are based on biological processes and recombinant DNA technology[49]. Although biotechnologies and biological manipulation have been applied throughout human history the advent of "modern biotechnology" is a more recent event which dates back to the discovery of the structure of the genetic code (DNA) by Watson and Crick in 1953. This was later followed by the development of recombinant DNA, also known as genetic engineering, in the 1970s. Along with these discoveries came expectations of an enormous potential to improve therapies and products in medicine, the healthcare sector, agriculture and so forth. Also, commercial and industrial expectations on developing industrial applications related to biotechnology grew stronger and in the late 1980s biotechnology was receiving growing attention as a promising business area. By the 1990s, biotechnology was receiving appraisal as the next big general purpose technology, with optimism among investors, policy organizations and governments concerning the possibilities of creating new economic resources and prosperity (Grace, 1997; Robbins, 2000; Pisano, 2006).

[48] For example, Biopolis in Singapore or Cambridge Science Park to mention a few.
[49] According to the Taiwanese government "Biotechnology is a set of powerful tools that employ living organisms or parts of organisms to make or modify products, improve plants or animals, or develop microorganisms for specific uses. Examples of this new 'biotechnology' include industrial use of recombinant DNA, cell fusion, and novel bioprocessing." (Biotech East, Internet)

The emergence of a Taiwanese biotechnology industry

The potential of biotechnology has not been overlooked by the Taiwanese government, which in the mid-1990s started to aggressively promote the field. Biotechnology had however already been noticed by Taiwanese policymakers in 1982 when it was identified by the government as one of the eight key technologies of the future. In 1984, a non-profit research institute, the Development Center for Biotechnology (DCB), was established. Commissioned by the government to promote the development of biotechnology in Taiwan, the DCB was modelled after ITRI. Not long after, the first biotechnology company, Paoshen Pharmaceuticals involved in vaccine production was founded. A second biotechnology company was also established shortly thereafter (Interview, Chester Ho; MOEA 2008a). According to Lee Chong Chou, the Director of the Biotechnology Office at STAG, these activities were the only commercial attempts in the biotechnology field:

> There were no real attempts of the government to really promote the biotechnology at the time. There were only two biotechnology companies prior to 1995 and the DCB did not have much success in help towards developing an industry. (Interview, Lee Chong Chou)

In the 1990s an increasing volume of expert opinions were voiced towards Taiwan needing a drastic change in industrial direction, as the electronic and semiconductor industries were becoming mature. An important message that was brought forward among policymakers was that in order to not fall behind the development of advanced countries, Taiwan needed to re-direct development to some more knowledge intensive sectors. The field which received most attention was biotechnology (Gwynne, 1991; Cyranoski, 2000; MOEA, 2003a).

It would take until 1995 before some dedicated policy attempts to push the Taiwanese biotechnology industry forward were initiated. In that year the Taiwanese parliament approved a promotion plan for supporting the biotechnology industry, also known as *the first promotion plan for biotechnology*[50] (MOEA, 2003b). At the time the two biotechnology companies had already gone out of business, and the DCB had been heavily criticized for failing in its mission to establish a biotechnology industry (Interview, Chester Ho). One commentator explains the situation in the following words:

[50] In the first promotion plan five major areas of attention were targeted: 1) Related Laws & Regulations; 2) R&D and Applications; 3) Technology Transfer & Commercialization; 4) Investment Promotion & Incubation; and 5) Biotech Service Industry & Industry Promotion.

> In some cases, the government has had to reconsider its approach. The Development Center for Biotechnology, established in 1984 when Taiwan first started to make its biotechnology push, was almost universally discredited for failing to build homegrown business (Harris, 2002:p600).

Hence the view brought forward is that when the first promotion plan was accepted through a referendum in the Taiwanese parliament in 1995, there was basically no biotechnology industry in Taiwan. The biotechnology industry emerged in Taiwan after the mid 1990s through the government's extensive support and coordination. Since the first promotion plan for biotechnology, the Taiwanese government has devoted a considerable amount of resources into the life-sciences and biotechnology. Revisions of the promotion plan have been made on a bi-annual basis, and to date the expansion of the biotechnology industry in Taiwan has continued to be an issue of direct government intervention. A quote from an online information provider on Taiwanese biotechnology, *Biotech East,* comments on the government's imperative role in planning biotechnology development with the following words:

> The strategy and direction of Taiwan's biotechnology industry development is clear and focused. Industry, institutions and government bodies all follow developmental guidelines as set forth in the Promotion Plan for the Biotechnology Industry. This document, a road map defining national industry goals and clearly detailing the corresponding action steps required to get there, was first written and released by the Executive Yuan branch of the government in 1995, and has been revised biannually ever since (Biotech East, Internet).

The ambition to focus on developing knowledge-based industries in order to maintain economic competitiveness was further strengthened when in 2000 President Chen Shui Bian[51] proposed to transform Taiwan into a *Green Silicon Island.*[52] This provided additional fuel for

[51] The Democratic Progressive Party's Chen Shui-Bian (in office 2000-2008) declared in his presidential inauguration speech that Taiwan should concentrate on knowledge based sectors in order to maintain economic competitiveness and sustainable development. The goal was to transform Taiwan into a "Green Silicon Island". (Chen Shui Bian, Internet).

[52] The Council for Economic Planning and Development of the Executive Yuan initiated the 'green silicon island' plan in February 2001. The plan is based on three major concepts: a knowledge-based economy, a sustainable environment, and a just society. The plan is implemented under seven principles: (1) increasing knowledge, (2) using resources effectively, (3) prioritizing environmental protection, (4) upholding justice, (5) promoting regional balance, (6) strengthening cooperation, and (7) expanding the economy. (Government Information Office (1), Internet)

the enlargement of the biotechnology sector. In August 2001, Chen also proclaimed biotechnology as the most important industry for Taiwan's future economic development (Wong, Internet). Consequently, in the *Six-year national development plan* of 2002 biotechnology was made one of the pillars of national development and a part of the *Two trillion twin star project.* The focus of this project was four specific industries, the Trillion industries: *semiconductors* and *digital display*; and the Twin stars: *biotechnology* and *digital content* (MOEA, 2006). Table 5.1 shows the specific economic goals for each industry set up by the Taiwanese government and the production value of the industries in 2006.

Table 5.1: Two Trillion Twin Star Industries - Status as of 2006 and goals for 2009

Industry	**Year**	**Production value**
Semiconductors	2006 2009	1.39 trillion NTD 256.1 billion NTD
Digital display	2006 2009	1.27 trillion NTD 1.6 trillion NTD
Biotechnology	2006 2009	177.5 billion NTD 256.1 billion NTD
Digital content	2006 2009	341.2 billion NTD 515 billion NTD

Source: (MOEA, 2007)

As reported by the MOEA, the high profile support of the biotechnology industry in Taiwan has resulted in an accelerated pace of development. In Table 5.2 below the results in terms of number of companies and revenues among other metrics for the biotechnology industry, which by the government's definition also includes pharmaceutical and medical device companies, are shown.

***Table 5.2: The Taiwanese biotechnology industry (2005/2006)* * in Billions USD**

Industry	**Biotechnology**	**Pharmaceuticals**	**Medical Devices**	**Total**
Revenue*	1.21/1.33	1.95/2.03	1.84/2.14	5.00/5.51
Number of companies	253/268	419/368	484/500	1156/1136
Size of work force	8090/8570	14995/12224	15000/16350	38085/37114
Domestic Sales/Exports	60:40/60:40	82:18/79:21	54:46/58:42	66:34/66:34

Source: (MOEA, 2008a)

Policy strategies to develop a biotechnology industry

As noted, the Taiwanese government has played an active role in the emergence of a biotechnology industry in Taiwan. The government's major strategies in developing biotechnology have been targeted at promoting specific scientific fields as well as biotechnology business in general. These government efforts are described through the quote below in an article in *Taiwan Review*, published by the *Government Information Office*

> Biotechnology is all the rage in Taiwan today, and runs through the industry from upstream basic research to downstream commercialization. In Taiwan, upstream actors such as Academia Sinica and university laboratories participate in various National Science and Technology Programs administered by the National Science Council. Midstream organizations are responsible for turning basic scientific research into usable technology and then into commercial commodities, or more succinctly, technology transfer. […] Public policymakers have also worked hard in recent years to rework the legal and regulatory infrastructures, tightening up some areas to bring Taiwan in line with international standards, such as in intellectual property protection, while beginning to relax other areas in order to promote more attractive investment and research environments. For its part, the government has attempted to facilitate innovative science and entrepreneurial bio-business in Taiwan. (Wong, Internet)

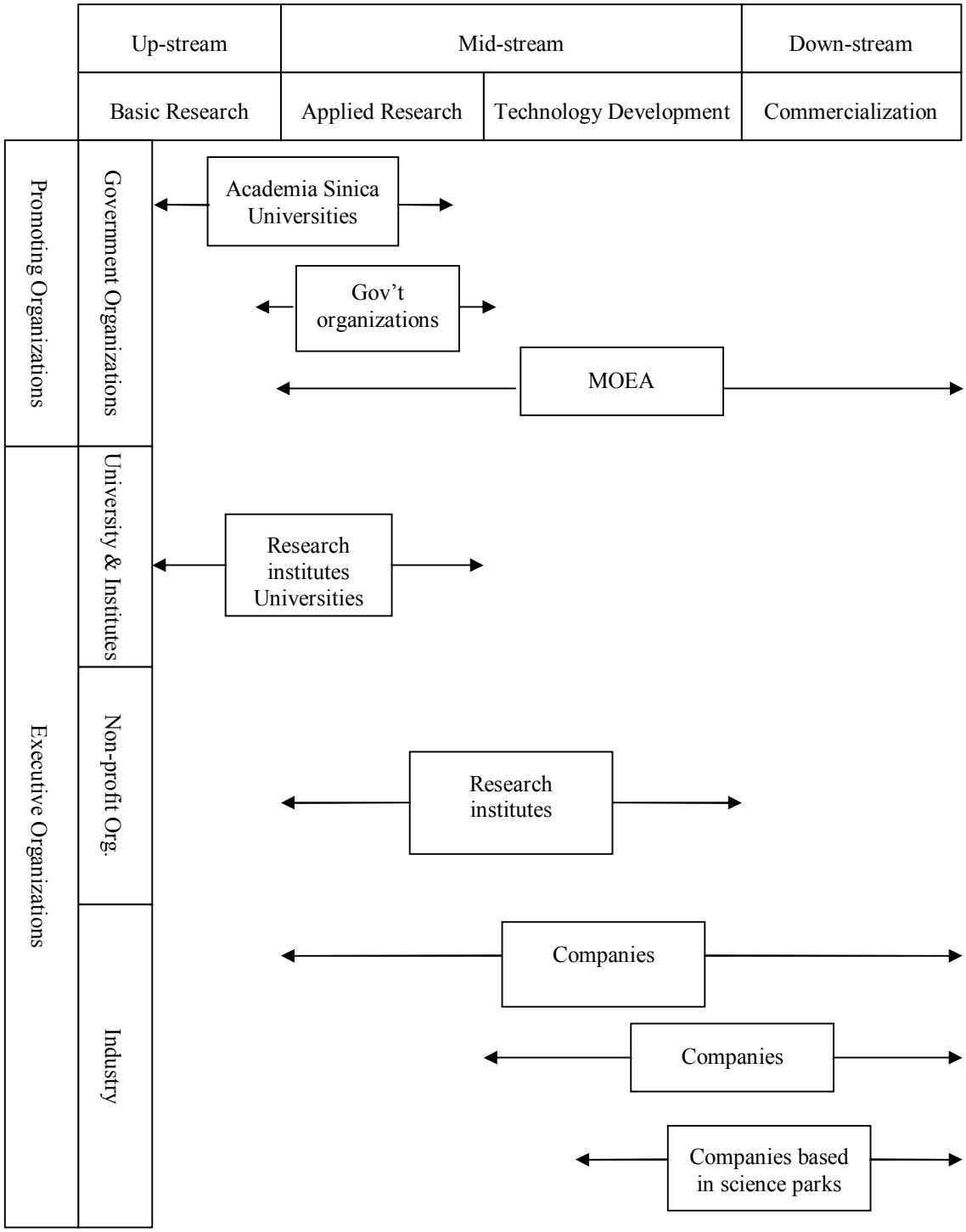
As the above quote reflects, Taiwanese policymakers are aiming at developing three levels, "upstream", "midstream" and "downstream". At the upstream section, universities and research institutes, i.e. organizations performing basic research are identified by policy as the major actors and are the subject of government guidance. The promotion of scientific areas considered by the government to have commercial potential has been given special attention (Campbell, 1997). At the midstream level, that is to say applied research, there are various government agencies identified as central and involved in the development of the Taiwanese biotechnology industry. These are intended to function as the intermediary step between basic research and industry. These research institutes are supposed to source, develop and absorb technologies from abroad and local universities. When these technologies have been developed they are to be transferred to the industry for commercialization. At the downstream level, company creation has been emphasized with start-up companies emerging from universities as well as the private sphere. A number of established companies have also been encouraged to diversify into biotechnology or to change their line of business given the

generous government incentives (MOEA, 2008a; Interview, Julie Sun). Some of these incentives are described by Wong (Internet):

> The Ministry of Economic Affairs offers tax-relief benefits for new biotech businesses, offsetting start-up costs and the depreciation of capital investments over time. In order to promote technological innovation in the biotech field, the ministry provides incentives (both tax-based and subsidies) for new product R&D, particularly for small and medium-sized enterprises.

In addition to providing support and direction to upstream, midstream and downstream sectors, there are also efforts to create interaction and connections between them. For this purpose, the government is particularly active in providing incentives. Taiwanese policy has for example established a number of science parks, new research institutes with open-laboratory policies, and incubation centers to function as hubs for upstream, midstream and downstream collaboration. Collectively, the science parks and research institutes function as a general infrastructure, implementing government policies and supporting the Taiwanese biotechnology companies as well as research institutions (MOEA, 2003a; 2003b). Science parks are established all over the island to consolidate research, development, and commercial actors spatially. In each area, universities, research institutes and other research organizations are encouraged by the government to concentrate on specific areas in biotechnology. For example, in the Taipei area with Academia Sinica, the Yang Ming University, the Nankang Science Park and the DCB the concentration is on drugs development. In Southern Taiwan the universities, research institutes and the Southern Taiwan Science Park concentrate on floriculture (MOEA, 2006; Interview, Wu Rong Tsun). In Figure 5.1 below the different organizations that policy has involved in promoting and developing biotechnology, including their roles, are illustrated.

Figure 5.1: Organizations involved in the development and promotion of biotechnology



Source: Modified from MOEA (2008a)

As the figure above shows the Taiwanese government is concerned with promoting three levels of the biotechnology industry – upstream, midstream, and downstream sectors. Below government policy at each sector is discussed.

Upstream sector: As described earlier a doctrine that has been guiding Taiwanese industrial policy in the last few years has been the need to concentrate on innovation in order to transform Taiwan into a competitive advanced economy. In a report from MOEA (2006: p12), some specific policy strategies to achieve this goal are: To "develop first-class manpower and reinforcement of innovative R&D"; to "create elite universities and R&D centers" and; to "invest in knowledge industries and development of culture and innovation". For these ends, the Taiwanese government has since the mid-1990s provided increased funding to the academic sector and other institutions that perform basic research. From the statistics provided by the National Science Council (2002), public spending on R&D has increased steadily since the late 1990s. For example in 1996 the government invested 57 billion NTD (approximately 1.7 billion USD) in R&D, and by 2001 this number had grown to 76 billion NTD.

The results of these investments have been measured in the number of academic publications listed in the *Science Citation Index* and the number of patents granted. As reported by MOEA (2008a: p5): "Basic research within Taiwan's biotech sector is rapidly reaching international standards. The number of patents granted, technology transferred, and the number of scientific papers published has been increasing each year". A large part of the increased public funding has been with the purpose of supporting certain research areas which the government considered as valuable for the industrial sector. (National Science Council, 2005)

To induce innovation for business and entrepreneurship in the academic sector, the university system has also been reformed. For example, in 1999 Bayh-Dole inspired legislation, *The Science and Technology Basic Law*, was enacted in Taiwan. This meant that the intellectual property ownership rights of discoveries made from publicly funded research were given to universities[53]. In addition, technology licensing offices and business incubation centers were established at Taiwan's main research universities (Hsiao Kuan Hsiu, Internet).

[53] The Bayh Dole Act of 1980 gave US universities the intellectual property rights to the inventions and discoveries made as a result of publicly funded research. The idea was that universities would have more incentives than the state to try to commercialize the intellectual produced at universities. Since then a large number of countries all over the world have followed the example of the US and enacted Bayh Dole inspired legislation.

In 2001, MOEA established the Academic Technology Development Program where the goal was to specifically direct academic research into industrial innovations. A main ambition declared was "to encourage educational institutes to combine their established R&D capacity with the characteristics and needs of area-specific industries to develop and upgrade industrial technologies that meet the needs of local industries" (Department of Industrial Technology (7), Internet).

Midstream sector: To be able to transform the discoveries and inventions originating from basic research into benefiting the industry, the Taiwanese government has been building up an infrastructure, of research institutes, incubation centers and science parks. The research institutes have a central role, as exemplified in MOEA's Technology Development Program. They are to perform applied research, develop technologies and advance scientific discoveries that are sourced locally as well as from abroad. In other words they are supposed to serve as the intermediary bridge between basic research and industrial application (MOEA, 2003b). In Taiwan there are a number of research institutes concentrating on biotechnology as mentioned below:

> Labs at the National Health Research Institute (modelled after the American National Institutes of Health), the Development Center for Biotechnology, the Biomedical Engineering Center at the Industrial Technology Research Institute (ITRI), and the soon-to-be-formed National Research Institute of Agricultural Science are some of the actors that fulfil this midstream function. (Wong, Internet)

In addition to establishing a number of new research institutes for promoting the development of biotechnology, the government has also dedicated a considerable amount of resources to developing production facilities at existing research institutes. For example, the government has given National Health Research Institutes (NHRI) the directive to lead national vaccine research and production efforts, including setting up approved vaccine manufacturing laboratories and production plants. Similarly, the DCB is responsible for leading national development programs in biopharmaceuticals. As can be noted from the following quote from DCB's website the research institutes have an important formal role:

> Our main mission is to help shape and develop Taiwan's biotechnology industry through R&D, infrastructure-building and training programs. We play the crucial role of facilitator to promote synergy of governmental, academic and industrial efforts and serve as a bridge connecting Taiwan's biotech industry to the world. (Development Center for Biotechnology, Internet)

With the government giving the research institutes this central role in biotechnology, development academia as well as private companies are encouraged to interact and collaborate with the research institutes in their respective fields of expertise. A number of incubation centers have also been established at the research institutes, which are mostly located in the growing number of science parks established all over Taiwan. As commented on by Wong (Internet), these serve as major hubs for biotechnology development:

> The government has earmarked over US$1 billion for investment in biotech, of which a significant portion has been going to the development of new biotech 'clusters' in Taiwan's science-based industrial parks.

Downstream sector: As can be viewed from Figure 5.1, the Taiwanese government's strategies to develop a biotechnology industry are quite straightforward. The universities and research institutes perform basic and applied research. These institutions however do not engage in wider extent in commercial activities, instead the research results are transferred to the downstream sector which consists of companies. The main functions of companies at downstream level are technology development and commercialization of technologies and products. In order to create an industry, the existence of companies is of course essential. The government plan has therefore emphasized the creation of domestic companies (Swirbanks, 1999). According to MOEA (2007), only two biotechnology companies had been established in Taiwan up to 1995, while in 2006 there were 268 biotechnology related biotechnology companies. How the Taiwanese government has achieved this is by providing financial and tax incentives for existing companies to move into biotechnology related activities. Another strategy have been through financially supporting new start-up companies, encouraging academic researchers to establishing their own companies, or for overseas Taiwanese professionals to return to Taiwan to set up companies. Although the numbers of companies has grown quickly, the quality of companies has not always been on a par with policy expectations. Thus in 2002, the government placed increased emphasis on creating companies

through spin-offs from the research institutes. The policy was drafted in the "Challenge 2008" project, approved by the Executive Yuan (the Taiwanese government's executive branch) in January 2003 (MOEA, 2004; Interview, Chiang Chih Lei). In an article in Nature, the following quote appeared, concerning this policy (Cyranoski, 2003: p673):

> Disappointment over a stultified biotechnology sector in Taiwan has led to a cabinet-level initiative to spin off companies from the island's research institutes. […] The initiative aims to produce 15 "successful" companies, meaning a market value of at least NT$2.5 billion (US$70 million) each, by establishing 79 spin-off projects over the next six years. The program will pour NT$9.4 billion (US$270 million) for the first three years, and at least the same amount in the next three years, into projects that will develop technologies from the Industrial Technology Research Institute (Hsinchu), the Development Center for Biotechnology (Taipei), Academia Sinica (Taipei), universities, and other research institutes. A significant portion of the new projects, for which the government will provide up to 45% of the start-up funding, will probably involve technology transfer from, or collaboration with, foreign companies, which can also use the project to establish branch offices on the island.

To promote technological innovation in the downstream sector has been one of the government's main priorities. Taiwanese policy has provided monetary support and a large number of other incentives to companies wanting to make R&D investments and perform innovation-intensive activities. However internal R&D is only one way to develop new solutions. Hence a government policy that has been strongly promoted is to stimulate collaboration between biotechnology companies and the midstream and upstream actors. For example, companies are strongly encouraged to collaborate with research institutes through open laboratory activities, or to take over technologies developed at the research institutes (MOEA, 2006; 2008a). Another issue of special importance has also been to increase collaboration between industry and academia. As the government organisation *Invest in Taiwan* noted, business-academia has improved in 2005. This was described through these words:

> In the World Economic Forum's Global Competitiveness Report, 2005-2006, Taiwan ranked 8th for collaboration among businesses and academic institutes. […] Taiwan's business sector values the effectiveness of joint R&D efforts. CEPD also stressed that research and development is the key to improving productivity and encouraging economic growth. More importantly, Taiwan is moving upward to added-value technology, high-density R&D and integrated logistics. Creating an optimal environment for the advancement of technology is crucial to this stage of development (Invest in Taiwan (1), Internet).

The Taiwanese government also gave the following comment about the advances in the biotechnology industry:

> Presently, the sector's upstream segment of academic research has reached international standards, while the midstream segment of development capability has also achieved a high level. As for the downstream segment, in addition to the existing 425 pharmaceutical companies and 380 medical equipment companies, over 100 pure biotech firms have been formed over the past three years, mostly focusing on R&D for biopharmaceutical products, health foods, herbal medicines, diagnostics, biochips, and agriculture (Government Information Office (2), Internet).

Summary

What have been portrayed up to now is a policy plan and ambition on how to promote biotechnology science and business in Taiwan. Some achievements of the government efforts have also been discussed. What can be observed is that the Taiwanese government has directed and supported development in three sectors. At the upstream level there are the universities and research institutes, midstream consists of research institutes, and the downstream level consists of companies. These sectors all have their specific roles in the development of biotechnology. The upstream actors are expected to conduct basic research; the midstream organizations are involved with applied research and; the downstream actors are to commercialize technologies and products which they have developed or acquired from midstream or downstream

5.2. Expectations on biotechnology not fulfilled

As has been demonstrated through government statistics, Taiwanese biotechnology has grown considerably since the mid-1990s because of the extensive policy support. In the National Development Plan for 2008 (CEDP, 2006: p26) it was expressed that the Taiwanese government is continuing this support and undertaking "effective measures to eliminate the knowledge, technology, and digital gaps" that are currently present. In a report on the investments opportunities in the Taiwanese biotechnology industry, the following could also be read at on the website of *Invest in Taiwan*:

> Taiwan's concerted policy efforts to develop research, development and production capabilities in the biotech sector have paid off in creating a wealth of investment opportunities. Biotech research at Taiwan's top academic institutions is gaining international attention, while development capabilities, fostered through joint industry and government support, are turning these research achievements into commercially viable products (Invest in Taiwan (2), Internet).

However, albeit the impressive growth of biotechnology in Taiwan, the industry has had difficulty in living up to the high expectations set by policymakers and investors. Even though scientific publications have increased, the academic sector has grown and a producing structure of domestic research institutes and companies has been built up, there are still several complications. The producing structure is still weak and a using structure of Taiwanese biotechnology products has yet to be clearly crystallized. The disappointment over the Taiwanese biotechnology is discussed by Hsu et al. (2005: p281), which provide the following description:

> Although the Taiwanese Government has put in a great deal of effort, the progress of biotechnology industry has not been as good as predicted. The total industrial output of Taiwan's biotechnology industry was less than 600 million US dollars in 2000, and most of the output was traditional bio-product related, rather than modern biotechnology products.

A similar opinion, that the Taiwanese biotechnology industry has not been fairing that well commercially, has also been brought forward in Nature (Swinbanks & Cyranoski, 2000: p422):

> Just as with electronics, the Taiwanese government has tried to develop biotechnology over the past two decades. But the results so far stand in stark contrast to the booming electronics industry. One only needs to look at Hsinchu to see the tiny contribution biotechnology makes 0.1% of sales and so far there is no sign of a major upswing.

Due to the perceived weak financial results as well as the modest technological outcomes, at least when measured in terms of the number of "breakthrough innovations", the government's polices have been challenged (Interview, Hubert Hu). A critique expressed by the following commentator has been commonly heard in the debate:

> The strategies of the government have not created viable businesses. Most businesses just get government support and would not survive without. They do not have any good technologies or any products which can be sold outside of Taiwan (Interview, Pele Chong).

Another common criticism of the method to create an industry is voiced by the Director of the Biotechnology Program at STAG:

> To support the biotechnology industry science parks have also been established all over the island, and in order to facilitate the commercialization process of scientific advances research institutes serve as the bridge between academia and industry. The technology transfer model has however not been working very well, but we are trying to change that (Interview, Lee Chong Chou).

Above, some of the reasons why the Taiwanese biotechnology has been seen as a disappointment were touched upon. For example, from investors' perspective, revenues from biotechnology are considered to be very modest, especially compared to the revenue levels achieved in the electronics or semiconductor industries. Thus few private sector investors have been willing to invest in biotechnology, and foreign multinationals have not been interested in establishing R&D or investing in Taiwanese biotechnology companies (Interview, Chen Chei Hsiang). Another perceived problem of the private sector investors was

that the majority of Taiwanese biotechnology companies were involved in "low-tech" biotechnology. Furthermore, the Taiwanese biotechnology industry had not yet produced "breakthrough" innovations or products (Interview, Chester Ho). This was also acknowledged by Taiwanese policy, as written in a report that argued:

> Like those in other industrialized societies, Taiwan's knowledge-intensive industries are facing a number of bottlenecks which may retard their pace of development. These include insufficient infrastructure, lagging technological innovation, a shortage of investment capital and high-tech workers, and an inadequate legal and regulatory structure. Such bottlenecks are of serious concern, since they affect Taiwan's capacity for innovation and its ability to compete with other nations (CEPD, 2006: p8).

The government's approach to solving these problems is to increase technological innovation. What is believed is that if new solutions and technologies can be developed they can also be transferred to the industrial setting through having a proper production structure. Use on the other hand is not clearly mentioned in government plans, but is treated as an exogenous factor, especially if the first two structures exist. What if we view the Taiwanese government's efforts to develop a biotechnology industry according to this template, through eyes within the industry? More specifically by taking a company's perspective in this case GE Healthcare[54], a world leading instrument supplier to pharmaceutical and biotechnology companies. The company has customers from all the three sectors, i.e. upstream, midstream and downstream. What is GE Healthcare's view of the three sectors and the government's efforts to create development, production and use of biotechnology in Taiwan?

A view from inside the biotechnology industry - GE Healthcare

GE Healthcare's main customers in Taiwan have been universities & governmental research laboratories for the smaller systems, and industrial customers and governmental research institutes for the larger systems. In 2005 academia accounted for 70 percent of GE Healthcare's business in Taiwan in terms of revenue, while the remaining 30 percent were

[54] GE Healthcare in Uppsala, Sweden (formerly Amersham Biosciences) is a part of the General Electric Company. Its main business areas are medical information technology and systems for the production of biopharmaceuticals. The Protein Separation Group within GE Healthcare develops and markets systems for large scale production of biopharmaceuticals and separation of proteins at a lab scale. GE Healthcare's turnover for 2006 was 14 billion USD, and 90 percent of all biopharmaceuticals available on the market use products from Protein Separations at least at one stage of their development (GE Healthcare, 2006).

industrial customers, including governmental research institutes. Five years earlier the division had been roughly 95 percent academia and 5 percent industrial customers. The 2005 numbers corresponded to about 500 academic and 20 industrial customers (Interview, Michael Chia; Interview, Lillian Wei).

The general upswing in GE Healthcare's business in Taiwan in the last few years has been due to the government's efforts to support the biotechnology industry. A large number of new customers have been found within academia, especially in Southern Taiwan. To promote an increased regional development, funding has been allocated to support the "less" developed areas in the south. A majority of the new customers are vocational schools and technical colleges that have been upgraded to university status. The government's focus on creating a *green silicon island* has resulted in more funding for biotechnology related university departments. These reforms comprise conscious efforts to build up human resources for the future in the field of biotechnology (Interview, Michael Lai; Interview, Lillian Wei).

There has also been increased business with the downstream sector. The companies that have business with GE Healthcare are almost all to a greater or lesser extent government sponsored. Many of these biotechnology companies have received government support for R&D activities and to purchase equipment but most of them lack product pipelines and viable projects. Since the government only supports companies with funding for up three to four years at a time, GE Healthcare has had difficulty in establishing long-term business relationships with these customers.[55] The ambition of GE Healthcare is to supply a company with equipment through the whole development process from laboratory work to production scale. For a drug development company, this means throughout the discovery, development and production of a drug. Through this, GE Healthcare generates business revenue by the sales of systems, but mainly through the sales of columns and media (i.e. consumables) (Interview, Ingemar Daniels; Interview, Lorentz Larsson; Interview, Annelie Sköld). However, few Taiwanese biotechnology companies have reached a stage where they need larger systems, i.e. for industrial production. For many companies, after the government funding expires there are difficulties attracting additional funds. As an extension, the government indirectly can be seen as the main customer to GE Healthcare (Interview, Lillian Wei).

[55] For example, to develop a drug and put it out on the market is process which takes usually 12-15 years for large pharmaceutical companies. As can be understood, 3-4 years is not a lot of time for drug development. Getting additional funding after the government grants are finished is a large problem for Taiwanese biotechnology companies, and several companies have gone out of business due to this (Interview, Lillian Wei).

The main business for GE Healthcare among the industrial customers is instead coming from the research institutes. In comparison to the private sector, most of the research institutes are non-profit organizations. As many of them are semi-governmental they enjoy continuous government funding. However, the inflow of projects to these institutes is modest. Given this situation for the industrial sector, the business for GE Healthcare is still uncertain. Instead of a dynamic industry with vibrant companies there are actually few biotechnology companies, specifically in the field of drug development, that do generate business for the world leading manufacturer of biotechnology equipment (Interview, Michael Chia). This situation is emphasized in the quote below from a sales representative of the company:

> Out of twenty industrial key account customers we only have regular business with three. We have sold systems to the other companies but don't really make any money out them. Right now we provide a lot of technical support but the business is irregular. I don't believe that we can expect that much more either in the next few years either, based on the companies' current projects and pipelines (Interview, Lillian Wei).

The picture of GE Healthcare's business activities in Taiwan corresponds to what the Taiwanese policy model has promoted. It suggests that biotechnology in Taiwan is very much government business. The government provides funding to actors in all three sectors involved in different aspects of development and production. Through the measures the government has been able to increase academic research, and to build up a producing structure of research institutes and domestic companies. The upswing in the academic sector has generated business for GE Healthcare and the research institutes are also growing. However the view of GE Healthcare is that it has not been a very vibrant producing structure, with viable biotechnology projects ready for commercialization. More importantly there are not many established relationships between producing and using structures. Consequently, as companies receive a considerable amount of government funding, many of them rely on this help as a lifeline. But as commented, once this support is withdrawn a majority of these companies would be out of business. Thus the Taiwanese industry consists of a number of nascent biotechnology companies with a very uncertain future.

This business reality expressed by GE Healthcare is in line with the disappointing picture provided by for example investors and industry commentators. The disappointment over the Taiwanese biotechnology industry is nonetheless nothing unique. All over the world, the high expectations of flourishing biotechnology industries has been an object of revision

(Waluszewski, 2004b). Developing commercial solutions in biotechnology is a highly risky and uncertain journey. It is subject to long development times, large financial investments, regulatory and legal issues just to mention a few hurdles (Pisano, 2006). But although empirical evidence suggests that creating science related high-tech industries is a daunting task, Taiwanese policy driven efforts remain strong.

Summary

Chapter 5 has portrayed Taiwanese policy efforts to create a biotechnology industry. As is evident, government policies are heavily influenced by the emergence of the semiconductor industry and its associated development model outlined in 4.2. With this inspiration, the Taiwanese government has taken a pro-active role in planning and guiding development efforts. For example, policy plans what research areas the upstream sector should be engaged in. Extended support has been given to those actors that are believed can create new knowledge and innovation. At the midstream sector, industrial technologies are developed and thereafter transferred to the downstream section. The government is quite explicit concerning what kind of companies to support, that will say the ones with innovative research.

Hence, the main components of the government recipe to build up a biotechnology industry have been to increase scientific production for biotechnology business; to support the "midstream" sector which uses academic research results for the development of technologies assumed useful in a commercial setting and; to support a company structure that can produce new solutions. However, what seems to be taken for granted by the Taiwanese government is a using structure that is assumed to adapt to what is developed and produced. The lack of users has also been shown to be problematic. Although the biotechnology sector in Taiwan has grown considerably after the first promotion plan for biotechnology was enacted, the commercial outcomes have not been on par with the expectations raised by investors and policymakers. This has resulted in a view that the biotechnology industry in Taiwan is a disappointment. According to policy, some of the challenges the industry is faced with are for example: the lack of technological innovation, a knowledge bottleneck, a weak technology transfer system, and a downstream sector that does not use research results from the upstream.

An analysis based on quantitative measurements of inputs and outputs, does not tell us the reasons why the connections between using structure and developing structures are weak. To understand this we instead need to go deeper in actual interaction processes. Another

perspective was therefore provided in chapter 5.2 to open up a view beyond the "superficial" indicators, such as number of academic publications, patents, academia-industry collaborations, and new companies. In a picture from the world's largest supplier of biotechnology equipment, GE Healthcare, we learned that there was growing academic biotechnology research and a large policy supported research institute sector, comprising the developing and producing structures. An increased number of companies were also undertaking activities related to production. But what can be understood from GE Healthcare's perspective is that the producing structure is weak and the connections to using structures are not particularly visible. What is suggested is that although development, production and use are rather different activities, they need to be integrated in order for innovation to come into being. Supporting development and production does not automatically result in commercial use. This issue will be exemplified in the next two chapters.

CHAPTER 6
A VACCINE AGAINST JAPANESE ENCEPHALITIS

In the following empirical chapters we will take a closer look at the processes where biotechnological solutions are developed, produced and used, including how these activities are related to each other. This is exemplified through two cases, where the first case concerns the development, production and use of a vaccine. The project initiated by the Taiwanese government has been considered as of central importance for Taiwan and has received much policy support. The second case looks at the development, production, and use of liposome-based biopharmaceutical drugs. The development and production of biopharmaceutical drugs is an area that has been prioritized by the Taiwanese government. The liposome project which is the subject of this study did however not entice any interest from policymakers and was not the object of any direct government support. From this short background, this chapter will present the attempts to create development and production of a biotechnology-based vaccine. In focus is a Japanese encephalitis vaccine project initiated and supported by Taiwanese policy.

6.1 A policy focus on vaccine development

From a public health perspective, vaccines serve as one of the strongest instruments of disease prevention[56]. To prevent epidemics, of vaccine-preventable diseases, breaking out and affecting a larger area, it is desirable for governments to exercise some control over the supply of vaccines. Traditionally the largest customers of vaccines have been public sector actors and international organizations such as UNICEF and WHO. Although vaccines are sought after market products, it has been difficult for smaller companies to make any major profits through vaccine development and business[57]. For a long time the vaccine market,

[56] Today there are three different types of vaccines: (1) Traditional vaccines (e.g. diphtheria, tetanus, polio, i.e., specific antigen vaccines), (2) Combination vaccines (DTP etc.), and (3) Vaccines for treatment of diseases.
[57] As stated by the WHO: "There are many companies producing vaccines but only a few meet internationally-recognized standards of safety and efficacy" (World Health Organization (1), Internet). Some of the reasons that have made vaccine production expensive and unprofitable for smaller companies are, for example, the limited market size (where vaccines are only used once or a handful of times for immunization), high barriers of entry in terms of expertise, and start-up costs (Salinsky & Werble, 2006).

mainly consisting of the production of traditional vaccines, has been dominated by a handful of large producers. In 2001 five companies accounted for 90 percent of total estimated world sales of vaccines (Advanced Immunization Management, Internet).

However since the late 1990s, a larger proportion of the private sector, including smaller companies, have also started to push the so-called "upstream development" of vaccines by introducing new technologies, and vaccine R&D has also experienced a surge due to the rise of biotechnology. As big pharmaceutical companies have continued to invest resources into the R&D of vaccines, more advanced vaccines have been developed. This has resulted in more efficient but also more expensive vaccines. In 2005 the sales of vaccines amounted to 6 billion US Dollars worldwide. This only represented 1.5 percent of total pharmaceutical revenues, but the vaccine market has continued to grow fast. Much of the growth is contributed to the development of new vaccines, either against diseases for which there is currently no immunization or for the development of second- generation vaccines against viruses such as influenza (Salinsky & Werble, 2006).

Vaccine development in Taiwan

In Taiwan, vaccine research and business has recently experienced a surge due to the government's ambition to create a vaccine industry, including development and production. The vaccine sector did not always enjoy government support, however, as is explained by the director of the vaccine center at NHRI:

> The local companies held only around 9 percent of the vaccine market in Taiwan and it was easier to import vaccines from abroad, with domestic manufacturers only having minimal government support (Interview, Pele Chong).

As can be understood from this quote, vaccines were an unpopular business for local companies due to limited market opportunities, hence public sector organizations assumed the main responsibility for providing vaccines. In 1952 the first state sponsored *Taiwan Vaccine and Serum Laboratory* was established with the objective to provide vaccines for the Taiwanese population. Efforts to set up R&D capabilities were also attempted, but they were unsuccessful and consequently stopped. The laboratory was reorganized several times and became a national institute in 1975. This was under the affiliation of the Department of Health, established in 1971, which is the highest authority in Taiwan on public health issues. In 1997

the responsibility for manufacturing and providing vaccines was delegated to the Centers for Disease Control (hereafter CDC). Soon thereafter the Department of Health commissioned the CDC to start developing new vaccines. Up to that date, no vaccines had ever been developed in Taiwan, and as mentioned, the private companies consisted of only a few small-scale vaccine distributors with little notion of R&D. There were therefore no laboratories or companies, private or public, that had been involved in any vaccine R&D prior to the initiative of the Department of Health (Interview, Pele Chong; NHRI (1), Internet).

The earliest attempt to develop a vaccine in Taiwan was made by the CDC in 1998 with a vaccine against Japanese encephalitis. Since then, other vaccines have also been commissioned by the government. Today, vaccine development in Taiwan is, according to Taiwanese policy, a joint effort of research institutes and a handful of private companies. The government has taken the lead in guiding these development efforts and emphasized the need to create a domestic vaccine industry. For the implementation of this public policy, research institutes such as the CDC, the National Health Research Institutes (NHRI) and ITRI have mainly been engaged (CDC, 2007; Interview, Pele Chong; Interview, Chen Chei Hsiang). With the government's continued support of the vaccine industry, both financially and through infrastructure build-up, new business opportunities have also emerged for the private sector. The attempts to create a vaccine industry have functioned as a lifeline for some pharmaceuticals companies as well as a number of biotechnology companies to expand their businesses (Biotech East (2), Internet).

In spite of the government support, there are still no vaccines in the development pipeline that have reached clinical testing stage and the market opportunities are still limited. In Table 6.1 below an overview of vaccines currently under development is provided.

Table 6.1: Vaccines under Development (status as of 2008)

Type of vaccine	Influenza	JEV	EV71
Unit	1) NHRI (developing a cell-based vaccine, H5NI) 2) CDC (developing an embryo based vaccine, H5NI) 3) ITRI (Tamiflu)	CDC/NHRI	CDC/NHRI
Stage	Pre-clinical testing	Pre-clinical testing	Pre-clinical testing
Starting year	1999	1998	2002
Partners	Public tender will decide a partner for production	ADImmune licensed the vaccine earlier.	Public tender will decide a partner for production

Source: Interview, Pele Chong

As can be viewed from Table 6.1, the development of vaccines has been conducted at Taiwanese research institutes. The origin of the production method or technology used for development has however come from various sources. There were of 2007 three different categories of vaccines (Influenza; Japanese encephalitis; and Enterovirus 71) in the development pipeline. None of the vaccine candidates had entered clinical trials by 2008 and efforts to include private manufacturers in the development and production processes had not resulted in any widespread collaboration. Although the vaccines are at a nascent stage of development, plans for technology transfers to the private sector had been planned out or already implemented[58]. The vaccine against Japanese encephalitis was the first which was commissioned by the Taiwanese government. With this background we will in the next section take a closer look the development of the Japanese encephalitis vaccine.

A policy ambition to develop vaccines

The introduction of a national vaccination program in Taiwan in the early 1950s had been successful in controlling diseases such as diphtheria, polio and tetanus among others. The

[58] For example for preventing a flu epidemic a vaccination center will be established by 2009. The proposal is to have a model based on Build Operate Own, where private companies will be responsible for building the centre, manufacturing the vaccines, and will then run the daily operation of the centre. The government's involvement would be limited to monitoring the operations. The rationale for a BOO solution has been to ease financial pressures on the government and to include private companies in the development of the industry. In addition, the government has also offered incentives to attract foreign manufacturers to set up operations in Taiwan. With incentives including guaranteed purchase contracts from government health authorities, local producers stand to benefit (Interview, Chen Chei Hsiang).

vaccines used were all imported from abroad and distributed to local government for administration. Although import was a viable option, building up a national capacity in vaccine development and production was something which was becoming more important for Taiwanese policymakers in the 1990s. The reasons were the expected global shortage in supply of these vaccines in the future and concerns about possible outbreaks of endemic diseases such as Japanese encephalitis, EV 71 infection[59] and influenza. The directive to start conducting vaccine R&D also came at a time when the Taiwanese government was building up a biotechnology industry. Thus supporting the emergence of local vaccine development and production would have benefits for the local pharmaceutical and biotechnology industries. Initially the main focus was on developing vaccines for infectious diseases that had a high incidence rate in Taiwan (CDC, 2007; Interview, Chen Chei Hsiang).

The goal was to become self-sufficient in what was considered vital vaccines for the Taiwanese population. The ambition of Taiwanese policy was both ambitious and challenging. There had not been any attempts to establish a vaccine industry prior to this stage, and no private companies in Taiwan had any vaccine R&D capabilities. Neither did the research institutes have much prior experience of vaccine research or development to continue building on. Although public institutions such as CDC or ITRI had competent academic researchers, few had experience of developing or commercializing vaccines or other biologics. The major measures in the government's plan were to assign the research activities to public research institutes. Marketing and distribution would later be the responsibility of the private sector (Interview, Pele Chong; Interview, Liu Ding Ping).

It was the CDC and the recently created vaccine center which was assigned the responsibility to develop a Japanese encephalitis vaccine. The idea to have a Taiwanese center for research and development of vaccines, had already been proposed in 1992 by the Department of Health. However it was not until 1997 when the Executive Yuan, the highest executive organ of the Taiwanese state, decided that the CDC could start to conduct human vaccine manufacturing. To undertake this task, the vaccine center was set up as an individual research unit. This unit was established through a reorganization of an existing structure of Taiwanese state laboratories and institutions, which were involved with vaccines in some capacity. Some of these had already existed for over 50 years, but none of them had been involved with vaccine development. The new vaccine center actually formally preceded the CDC, which was officially established in 1999. The departments that make up the current

[59] In 1998 there had been an outbreak of EV 71 in Taiwan resulting in 78 deaths (World Health Organization (2), Internet).

CDC had of course existed earlier. The new CDC was merely a reconfiguration of several public research divisions and laboratories under one roof. The goal was to gather the public organizations involved in promoting national health through the usual channels such as disease information to the public, active involvement in disease scenarios involving both prevention and implementing control measures against disease outbreaks. The CDC was structured with nine different divisions and six branch offices, and the vaccine center was also reorganized under the CDC umbrella (CDC, 2007; CDC, Internet).

There were several obstacles to be circumvented for the vaccine center in the beginning. For example, as mentioned earlier there was no vaccine industry in Taiwan at the time and all the vaccines were imported from abroad, mainly from Japan, Europe or the US. Experienced and competent personnel in vaccine development were difficult to find in Taiwan, as well as local partners, including private companies and universities (Interview, Liu Ding Ping).

6.2 The first project – A vaccine against Japanese encephalitis

The first project at CDC's vaccine center was targeted at developing a vaccine against Japanese encephalitis[60]. The plan to initiate development of a Japanese encephalitis vaccine had come from officials at the Department of Health. Although a large proportion of the Taiwanese population had already been vaccinated against Japanese encephalitis it was still considered a troublesome disease which caused occasional outbreaks in Taiwan (Interview, Liu Ding Ping; Interview, Lillian Wei). At the time there were three vaccines that were available for use worldwide: (1) an inactivated mouse brain-derived vaccine; (2) a vero cell-derived inactivated vaccine and; (3) a live attenuated SA14-14-2 vaccine. Of these three, only the inactivated mouse-brain derived vaccine (Nakayama strain) was internationally registered and had been used over an extended period of time (World Health Organization (3), Internet).

It was the mouse-brain derived vaccine which was used in Taiwan. The national Japanese encephalitis vaccination program in Taiwan had already started in 1968 by the Taiwan Serum and Vaccine Research and Production Bureau. The program targeted foremost endemic areas, and with immunization rates of up to 80 percent the numbers infected had

[60] The Japanese encephalitis virus, transmitted to humans through mosquitoes feeding on infected wild birds and pigs, is prevalent over a vast geographic area including China, India, Japan, Taiwan and most other areas of South Eastern Asia. Around 30000 to 50000 cases of Japanese encephalitis are reported every year worldwide and there is a 30-35 percent fatality rate. For the survivors, a large proportion also develops neurological and psychiatric disorders. In the absence of drug therapies, vaccination[60] against Japanese encephalitis has been the most efficient control measure (World Health Organization (3), Internet).

dropped to less than 40 cases annually by the 1980s (Yang et al, 2006). The problem associated with the mouse-brain derived inactivated vaccine was however that it did not yield long-term immunization. Continued vaccination at regular intervals was therefore needed for extended protection. Moreover, manufacturers of this vaccine were scaling down their production as newer Japanese encephalitis vaccines with fewer side effects were being developed, although still not yet available on the market (Beasely et al. 2008). This meant that there would be supply problems in the future. Hence an objective for the Taiwanese government was therefore to develop and produce a Taiwanese made Japanese encephalitis vaccine in large enough quantities to address at least acute shortages in supply.

In 1998, a year after the directive from the Department of Health, a research group at the vaccine center started the first attempt at formulating a Japanese encephalitis vaccine. There were several approaches to developing a Japanese encephalitis vaccine. The most common used method was to grow the virus in a mouse brain and then inactivate it in formalin. Since this method of developing a Japanese encephalitis vaccine had a proven track-record it became a safer choice for the CDC to start with. Despite the general trend moving towards developing newer and more advanced Japanese encephalitis vaccines the vaccine center at the CDC did not posses the expertise or resources to develop advanced vaccines. The option of incorporating it through a technology transfer from a global vaccine manufacturer was of course not economically viable, and did not correspond with the guidelines set up by the Department of Health, which was to produce a vaccine that was safe, efficient and possible to develop and produce within a reasonable amount of time (Interview, Liu Ding Ping; Interview, Chang Rai Yuan).

Given the policy directives the possibility of developing a second generation Japanese encephalitis vaccine was not likely as the commitment in time and resources would be substantial. Since the CDC did not have the capacity for developing vaccines with novel technology and the vaccine center could not financially commit to a technology transfer of an advanced vaccine the option to use a standard and mature method seemed quite fitting. As mentioned, the method had been used for a long time and proven effective in providing protection against Japanese encephalitis infection. The main purpose of the CDC was after all to develop a vaccine which would be accessible, cheap and safe. The researchers therefore believed that the mouse-brain derived vaccine would serve this purpose (Interview, Liu Ding Ping; Interview, Lillian Wei).

A proven method

The main objective at the first stage of vaccine development is to identify the micro-organism that causes the disease. The development becomes gradually complex for each step thereafter. A concept of how the vaccine will affect the body needs to be outlined. For this the research team needs to have an understanding of how the vaccine candidate will provoke the immune system to start fighting the foreign invader, i.e. the pathogen, which is a bacteria or a virus. All vaccines focus on the immune system's natural ability to fight off foreign bodies. The purpose of a vaccine is to bring immunity by activating the immune system to fight the pathogen that causes the disease. In a vaccine, the disease agent should of course be much less potent than the real pathogen, but at the same time elicit a response from the immune system. After understanding the development at a conceptual level, the next step is to culture sufficient quantity of the virus in order to test the concept[61]. After the virus has been purified and obtained in sufficient quantities, it is inactivated. At this stage the vaccine candidate is ready to be tested on animals. The first tests involve the safety and immunogenicity experiments. The issue of interest is if the vaccine candidate elicits an immune response in the test subjects, and if it is safe enough to administer to humans. To reach clinical trials, a working animal model and proof of concept is required. The protocols acquired through the animal testing make up the basis of evaluation from the principal investigator to obtain consent from authorities for a continuation of the vaccine project (Salinsky & Werble, 2006, Interview, Lee Min Shi).

Proper protocols were followed by the researchers at the vaccine center, and most of them had extensive experience in laboratory work. A virus bank was created through growing the Japanese encephalitis virus in mouse brain. The vaccine center had already acquired several chromatography systems from GE Healthcare (at that time Amersham Biosciences), and the purification of the virus was performed by using the ÄKTA Explorer[62]. Later larger systems for industrial production, which complied with the sanitary requirements of the FDA were also purchased. The inactivated virus was tested on mice, but initial results from the experiments revealed some severe side effects with the vaccine candidate. There had been

[61] For a better understanding of the development process, the different steps are outlined below (a template for the mouse brain inactivated vaccine): 1) Create a virus bank - the purpose here is to create sufficient quantity of the virus for use in vaccine pre clinical trials; 2) Virus concentration - growing the virus in the cell lines or in live animals; 3) Virus purification - extract the virus from cells or animals by using e.g. liquid chromatography; 4) Virus inactivation - damage the virus so that it cannot cause the disease for which it is intended to protect against; 5) Immunization - test in cell culture and animals whether the vaccine candidate can provoke the immune system to recognize the pathogen and achieve immunization (Interview, Chen Hsin Wei).

[62] A protein separation system used for middle-scale production.

some problems in purifying the virus, which had brought some unwanted adverse effects. It was on the other hand expected that there would be some complications and it is seldom that no problems are encountered at this stage. But the side effects were so severe that the researchers had to go back to the purification stage[63]. Despite the relatively large setback at this early stage, the mouse brain project was continued. After all, the CDC had instructions from the highest public health authority in Taiwan to develop a vaccine against Japanese encephalitis. Repeated testing did however not yield any improved results. The method of breeding the virus in mouse brain was also becoming expensive. The CDC had to keep 100,000 mice for research (also used in other projects), which was both costly and time consuming in maintenance. Furthermore, the use of mice to grow the virus was getting increased criticism from animal rights organizations. Later, in 1999, the CDC decided to terminate the mouse-brain derived vaccine project. However, another method to grow the virus in order to continue the quest for a Japanese encephalitis vaccine was needed (Interview, Lillian Wei; Interview, Chang Rai Yuan).

Since the results of the toxicology and safety tests of the initial vaccine candidate had not been adequate, the efforts would have to be concentrated at improving the safety profile. A technique which could potentially lead to a better result was the cell-culture based method[64]. The clear trend in the development of Japanese encephalitis vaccines had been to discard mouse-brain derived production of the virus in favour of cell-culture based production. The cell-culture based method introduced in the 1990s used artificially cultured cell-lines, usually kidney cells from mammals, to grow the virus. With this method the research team created another virus bank and continued the safety testing. The initial tests came back with improved safety profiles however the project had started to encounter some problems with funding. Even though the government was the financial sponsor, the funding was not by any means secure. Short-term political interests could easily change the budget situation of the public research institutes. In 2000 there were presidential elections, and during elections the research budgets had a tendency to shrink. With elections there would usually also be a change of the administration of the public research centers. Adding to the problem was also the

[63] The common impediments are usually due to problems in the purification process; it can also be a failure in the inactivation of the virus, where the disease agent might still be somewhat potent (in this case it can cause the disease it is suppose to prevent). In CDC's case it was an improper purification that had led to the severe side effects. The mouse brain is relatively well characterized with mice being the most common lab animal and much research has been done on the animal's anatomy. However, the risk of not removing all the unwanted substances that can possibly cause adverse effects when harvesting the virus is larger than, for instance, using an artificially created growth system (e.g. cell culture) (Interview, Sköld).

[64] The procedure is performed by injecting Japanese encephalitis virus into the cells for cultivation; the process then follows the same pathway as the mouse brain method: i.e. the virus is harvested, purified and inactivated.

inconsistency of allocation of funds to different areas of research, and a general confusion of what research should be undertaken at different research institutes (Interview, Pele Chong; Interview, Liu Ding Ping; Interview, Chang Ray Yuan).

Regulatory issues

The volatility in government plans was nonetheless something the management and the researchers at all the public research centers were accustomed to. Due to the problems with financing, the Japanese encephalitis project was delayed. Other problems also included the lack of qualified investigators and researchers that could guide the research team through the regulative issues. In order to obtain approval for a vaccine, at every stage, it needs to follow rigorous regulative procedures, for example equipment used needs to be approved and for this qualified engineers need to certify the research facilities among other things. The vaccine center did not initially have qualified personnel who could coordinate these processes (Interview, Pele Chong; Interview, Annelie Sköld; Interview, Liu Ding Ping).

The clinical development process for vaccines is the same as for biologics and drugs. A company or research institute (i.e. the sponsor) wanting to begin clinical trials with a vaccine must submit an Investigational New Drug application (IND) to the regulating authorities in the country in which the tests are undertaken.[65] If the IND is approved by the regulating authority (in Taiwan the Bureau of Pharmaceutical Affairs, BPA under the Department of Health[66]), the sponsor can continue to clinical trials. These clinical studies rely upon the participation of hundreds to thousands of people. Similar to drugs, a vaccine candidate undergoes three phases[67] of clinical trials before it can be considered for approval as a vaccine. If the clinical testing is successful, the sponsor of a vaccine needs to submit a license

[65] The purpose of the IND is to describe the vaccine, its method of manufacturing, and the types of quality control testing done prior to administering the vaccine to humans. Also included is information about the vaccine's safety and ability to trigger an immune response (immunogenicity) in animal testing. In addition, the IND contains the proposed clinical protocol (written description of a trial design) for a study in humans.
[66] The BPA approves and evaluates drugs together with the Center for Drug Evaluation (CDE) in Taiwan. The function of the BPA is similar to the US Food and Drug Administration (FDA).
[67] Initial human studies, referred to as Phase 1, are safety and immunogenicity studies performed in a small number of closely monitored test patients. Phase 2 studies enrol up to hundreds of test persons. Phase 2 studies often include dose-ranging studies (studies to evaluate the safety and immunogenicity of different vaccine doses). Finally, Phase 3 trials can sometimes enrol thousands of test patients and provide the critical documentation of effectiveness and important additional safety data required for licensing. At any stage of the clinical or animal studies, if information provided to the approving authority raises significant concerns about either safety or effectiveness, the authorities may request additional information or studies, or might halt ongoing clinical studies

application to the regulating authority[68]. During this stage, the proposed manufacturing facility also undergoes a pre-approval inspection, during which, development and production of the vaccine is examined in detail. The regulating authority can approve a vaccine for general use if it is safe and effective in preventing an infectious disease, and remains stable and potent during its shelf life[69] (FDA, Internet).

The research team which was developing the Japanese encephalitis vaccine consisted at the time mostly of university trained researchers. They did not have the industrial experience and the knowledge to navigate through the regulatory process, as was suggested by the following key account manager at one of CDC's suppliers of biotechnology systems:

> The problem was the researchers were not fully knowledgeable about the regulatory process. In order to develop vaccines, you need to stringently follow the proper protocols. You also need the help of engineers for certification. CDC did not have that capacity (Interview, Lillian Wei).

To move on with the development of the vaccine and attain the necessary documentation, the project needed to move into bio-safety testing. This would be of special importance, as safety is a main concern. At the pre-clinical stage, if the vaccine is not safe it will not be approved for testing on humans. The bio-safety results, including testing parameters in toxicology, microbiology and pharmacology are in this regard the most important information required for the regulating authority on making the decision whether or not to sanction the continuation to human clinical trials (Interview, Michael Chia; Interview, Pele Chong).

In 2001 the vaccine project progressed to a stage where it required bio-safety testing. An important consideration was to what level of rigor the bio-safety tests could be conducted. Since the experience of the research team was limited, there were concerns whether or not it would be sufficient to convince the authorities. The more rigorous the testing is, the better the chances of achieving an approval to move on. Since there was a lack of experience in the research team it could be a difficult task to get the vaccine approved to move into the next stage. The vaccine center employed mostly master graduates directly from university; few had

[68] This application is reviewed by a multidisciplinary team (composed of many types of specialists including medical officers, microbiologists, chemists, etc.) and includes information about efficacy and safety necessary to make a risk/benefit assessment and to recommend or oppose the approval of a vaccine.

[69] Of course no vaccine is perfectly safe. No matter how extensive the testing is, it is impossible to account completely for the big variation among individuals, their immune systems, and their reactions to the introduction of new substances into their bodies. The approving authority monitors vaccine distribution and use and collects information on adverse reactions to vaccines, even after they are licensed for use by the general public.

actual working experience in the industry and their laboratory experience was limited to the usual small scale laboratory exercises. The senior researchers overseeing the work also had little or no practical experience in vaccine development. Partly because of the in-experience the progress of CDC's Japanese encephalitis vaccine was temporarily halted in 2001 (Interview, Lillian Wei; Interview, Chang Rai Yuan).

A new policy direction for the Japanese encephalitis vaccine

The development had been more problematic than initially expected. In order to account for the loss in time and to put the project back on track the Department of Health promulgated a new strategy. The CDC was to open up the project for public tender and the vaccine candidate was to be licensed to a company capable of completing it. The CDC would still provide technical support, and the government was to support the project by providing financial means to the company willing to license the vaccine. This was believed by policy to be an opportunity to ignite the domestic industry. After all, one of the goals of the government was to build up a national capacity in vaccine development, including the participation of the private sector. In such a scenario the government would also save money at the production level. For example the fixed cost components in making a vaccine are quite large, consisting of costs involving R&D, and clinical trials. In addition there is a large overhead in having to build vaccine plants, the operation and maintenance of facilities, scale up production, logistics, distribution et cetera. The preferred mode of development was therefore, from the perspective of the government at this stage, to include private industry before commencing the large-scale production stage. The private sector was believed to have more incentives to commercialize vaccines, although there were no companies with vaccine R&D and manufacturing experience (Interview, Chen Chei Hsiang; Interview, Liu Ding Ping).

The strategy which the government promoted was a technology transfer model, with public research institutes transferring technology to the private sector. As mentioned earlier, it was this recipe that was assumed to have set the foundation of a successful semiconductor industry and that was now applied to the biotechnology industry. Of course the policy officials did not believe that it would be an immediate success. The Japanese encephalitis vaccine was still at a very early level of development, but Taiwanese policymakers were becoming increasingly impatient with the slow progress and something radical had to be done. Three years had passed since the Japanese encephalitis project began, and the results were less

than impressive according to state officials. Although at the same time it was perhaps naive to expect the researchers at CDC to come up with a vaccine, given the situation. How would a few inexperienced researchers at CDC be able to develop a vaccine within a few years in an infrastructure not yet built up? Hence it was believed that a for-profit organization would have more incentives to finishing the vaccine (Interview, Chen Hsin Wei; Interview, Chang Rai Yuan).

In 2002 CDC's Japanese encephalitis vaccine was opened for a public tender coordinated by the MOEA. The applicants would be jointly screened by the CDC and the Taiwanese government. The candidate that had the best technological and organizational capacity to develop and commercialize the Japanese encephalitis vaccine would obtain the licensing rights. The selection process never became a difficult issue though, because only one company, ADImmune, was interested in licensing the vaccine. For only 1 New Taiwan Dollar, ADImmune was able to license the rights to the Japanese encephalitis vaccine. In the technology transfer agreement that was negotiated, the company would receive the exclusive right to the vaccine candidate and the financial and technical support needed from the government to continue the development (Interview, Pele Chong; Interview, Liu Ding Ping).

ADImmune was the only private sector human vaccine distributor in Taiwan at the time. With its origin in Kuo Kwang Serum and Vaccine Laboratories the company had been established in 1965 with the help of the Kitasato Institute[70]. ADImmune was already selling a Japanese encephalitis vaccine on the Taiwanese market, which had been licensed from the Kitasato Institute. Even though the company was promoted as a vaccine manufacturer, it did not have a R&D department at the time. The business was basically evolved around importing bulk vaccine for distribution in Taiwan. The management of ADImmune was aware of the government's efforts to strengthen the domestic vaccine industry. As one of the major distributors of vaccines against Japanese encephalitis, tuberculosis, tetanus and flu in Taiwan, the government's vision was an opportunity for ADImmune to grow their business. Hence in 1998 the company had restructured and re-emerged as KuoKwang Biotechnology Company after some financial support from the Executive Yuan's development fund[71]. KuoKwang Biotechnology Company was later acquired by ADI Corporation, a computer hardware

[70] The Kitasato Institute in Japan was formed in the 1940s and is a major research institution in the field of vaccine research and development.
[71] The main government fund allocation funds to high-tech development projects.

manufacturer wanting to diversify into the high-profile biotechnology industry, and was as a result renamed ADImmune Corporation[72] (ADImmune, Internet; Interview, Lillian Wei).

By promoting itself as an innovative biotechnology company, ADImmune became eligible for a number of government support programs. Through this tactic, ADImmune gained attention from the government and was also becoming recognized in media as a promising biotechnology company. What the company wanted was to become the dominant vaccine manufacturer in Taiwan and to gradually establish business overseas. For this aim ADImmune needed not only be a distributor but also be strong in the R&D area. ADImmune had up to now solely been a distributor of vaccines, and the company enjoyed a steady stream of income in its capacity as the only private human vaccine distributor in Taiwan (ADImmune, Internet; Frost & Sullivan, Internet).

How the Japanese encephalitis focus came into the picture was because vaccines against Japanese encephalitis had received little priority from pharmaceutical companies. Hence if ADImmune could develop and produce a vaccine it would be one of few manufacturers to sell Japanese encephalitis vaccines. A problem was however, as mentioned earlier that the company did not until recently have any R&D capabilities. Despite this situation, ADImmune was promoted in policy circles and in the business press as a future company, and was praised for its business model (Interview, Chen Chei Hsiang). With the new opportunities, ADImmune had within a few years been able to position itself as a R&D driven company. With an ambitious marketing plan and an active collaborative strategy the company was amply rewarded by the government. ADImmune was awarded several rounds of government funding for the development of different projects including the development of a production facility for plasmid DNA; an entero-virus vaccine; a technology platform for DNA vaccines[73]; a Japanese encephalitis vaccine based on cell culture technology and; an influenza vaccine technology transfer from Kitasato. All these projects were initiated within just a few years of each other. (ADImmune (1, 2), Internet) Although the ambitions had been set high the vaccines projects were systematically delayed. For instance the development of a Japanese encephalitis vaccine using cell-culture technology had already started in 1998 but ten years

[72] At the end of the 1990s the biotechnology investments grew, with many non biotechnology/pharmaceutical related businesses investing in the industry. The biotechnology industry however suffered an investment relapse later, when it became obvious that the quick returns were not there. Many investors withdrew their commitments.
[73] DNA vaccine technology is the most recent approach in mobilizing the immune system against pathogenic invaders. DNA technology is however still a very experimental technique towards vaccines development. No successful vaccines based on DNA technology have yet been developed, and those that had been tested on humans had been shown to have an immunization effect of little practical use.

later the project was still in the pre-clinical stage74. The DNA vaccine was even further from away from being completed. The transfer of CDC's Japanese encephalitis vaccine was also considered a failure, from both sides (Interview, Lillian Wei; Interview Chang Rai Yuan).

A failed technology transfer

Already from the start there were problems with the transfer project. The first stage of the technology transfer was finished in 2004, but the management of ADImmune was not satisfied with the support they received. A problem was conflicting views between ADImmune, CDC and policymakers on how the vaccine should be developed. Furthermore, ADImmune did not see much economic potential in CDC's Japanese encephalitis vaccine and argued that it needed more resources for the development. The disagreements could not be dissolved and in addition both sides of the partnerships were experiencing budget limitations. As a consequence a second phase of the transfer was never completed (Interview, Lillian Wei; Interview, Chang Rai Yuan).

ADImmune had seemed more concerned with building a large project base. That these projects had a long way before being completed did not hinder the government to support the company. ADImmune was working together with research institutes such as the DCB, Academia Sinica, and CDC. It had also collaborative agreements with foreign organizations such as Kitasato institutes. The projects which were in the development pipeline were using advanced technology or were to develop novel products and technologies. But as the interactions with the vaccine center showed, ADImmune had not been as active finishing the projects as starting them. A similar picture of was also provided by one its suppliers, GE Healthcare through the following quote.

[74] Usually 7-13 years is given a as reference for the completion of a vaccine from development to a finished product.

> ADImmune did not acquire any of our chromatography systems until 2004, when they bought an ÄKTApilot. They have however not used it instead they have relied on the DCB in developing the plasmid DNA technology. … The researchers at the DCB are competent, they use the ÄKTA systems frequently and we don't really have to give them a lot of technical support. […] Our chromatography systems should also be frequently used if they (ADImmune) had actual vaccine production. But they don't buy a lot of consumables, which is an indication that they are not really using the systems (Interview, Lillian Wei).

The quote above from an interview with a sales representative of GE Healthcare implies that ADImmune had not achieved any significant milestones in the commercialization of their R&D. Most of the technologies and product candidates had been sourced from public research institutes and no vaccines in the development pipeline had yet entered clinical trials.

In 2006, four years had passed since ADImmune and the CDC initiated a technology transfer. CDC's vaccine center had commenced other projects such as the development of an enterovirus vaccine commissioned by the Department of Health. ADImmune, busy with building up its reputation as the major vaccine company in Taiwan had by this time received several rounds of government funding, for projects related to vaccine development. The company had however hitherto little to show for in the development department and the transferred vaccine project was only collecting dust. CDC's vaccine center and ADImmune had long before gone their separate ways and from 2004 there was basically no longer any interaction between the two partners. When it became clear to also policymakers that the development would not continue in the hands of ADImmune, the research team at CDC's vaccine center was yet again given the responsibility to continue the development in 2006. Basically the development of the Japanese encephalitis vaccine continued from where it had left off five years earlier, i.e. requiring bio-safety testing. In order to continue with the Japanese encephalitis vaccine development, the research group started to consider outsourcing the bio-safety testing in order to move forward. In Taiwan there were however no approved bio-safety testing facilities for vaccines (Lillian Wei; Interview, Chang Rai Yuan). In the quote below a sales representative from GE Healthcare talks about the choices the research group had.

> Of course the bio-safety testing could have been done by the research unit. The only instrument you need for the pre clinical is the ÄKTApilot[75]. At this stage there is not much required. The Taiwanese researchers are competent and they have lab experience. However they don't have the production experience and the experience in handling the authorities. Producing a vaccine does not only require a research unit but also administrative posts and also certifications and building up facilities which can be approved by regulatory authorities. In this respect it was better for the CDC to outsource the bio-safety testing (Interview, Lorentz Larsson).

With the help of Amersham Biosciences (nowadays GE Healthcare) contact with Bioreliance, a Scottish company performing bio-safety testing, among other services, was made. The company had extensive experience in bio-safety testing and had a cGMP approved plant. Although the service would cost a significant amount of money, Bioreliance was considered one of the best in the industry and the testing could be done properly (Interview, Michael Chia; Interview, Lorentz Larsson).

A new government policy – NHRI responsible for national vaccine production and development

While the CDC was working on getting the Japanese encephalitis vaccine candidate ready for bio-safety testing and approved for clinical studies, the government had drafted a new policy to develop and produce vaccines. A single vaccine center was to be created by merging CDC's vaccine center with the National Health Research Institutes (NHRI). The NHRI was established in 1996 by the Taiwanese government as a non-profit foundation with an aim to enhance medical research in Taiwan. Initially the NHRI was organized under Academia Sinica[76] and had a focus on basic scientific research. Today the NHRI[77] functions primarily as a research and development organization in national health issues (NHRI (2), Internet).

[75] Äkta Pilot is a protein separation system which is CGMP approved. It can be used at both laboratory scale and production scale, making it an important system for early stage projects moving into mid-stream level production.
[76] The Academia Sinica, headquartered in the Nankang district of Taipei, is the national academy of Taiwan. It supports research activities in a wide variety of disciplines, ranging from mathematical and physical sciences to life sciences, and also humanities and the social sciences.
[77] With the following purposes: To plan the overall directions of national science and technology development in health and medical care; To coordinate, integrate, and support research activities undertaken by medical institutions in this country; To further educate and train young scientists and physicians; To establish an objective and fair system for reviewing and assessing research projects and their progress; To facilitate the exchange of information and to promote domestic and international cooperation (NHRI (2), Internet).

As mentioned earlier, the idea of having a Taiwanese Vaccine Center for Research and Development was suggested already in 1992. In 1997 the CDC was appointed by the Executive Yuan to conduct the *human vaccine manufacturing plans*. By 2001 the Executive Yuan had appointed the NHRI to take over the human vaccine manufacturing plans. This new plan included the integration of CDC's Vaccine Center with the NHRI Vaccine Center for Research and Development. In 2002 the DoH approved the new NHRI Vaccine Center which started vaccine research and development activities in 2005 (Interview Chen Chei Hsiang; NHRI (1), Internet).

The ambition behind the merger of vaccine research at CDC and NHRI was to form a new stronger vaccine center combining the academic strength of NHRI with the personnel at CDC which had some practical experience in developing vaccines. The consensus among decision-makers at the Department of Health was that more intellectual and academic resources were needed if the vaccine development was to be successful. With increased intellectual capacity, the government also provided incentives for professionals from large global vaccine manufacturers to lead the Taiwanese vaccine initiative. Gradually the NHRI recruited professionals with industry experience, within Taiwan as well from other parts the world, most of them being Taiwanese nationals returning from overseas. In line with these developments the NHRI also upgraded its technical capacities and facilities for vaccine development and production[78] (NHRI (2), Internet; Interview, Lee Min Shi).

The process has however not gone as quickly as the government wanted. Some of the problems have included the lack of experienced research personnel. Inconsistency in government policy has also taken away time from the development and made it difficult to obtain steady funding. Even though the government is the main sponsor of vaccine projects, the goal of the vaccine center is to have a stable operation with a steady source of income from vaccine sales. After the merger with NHRI, the center will become semi-governmental. Nevertheless, since the CDC is fully governmental there are some problems which need to be solved before the two centers can be fully integrated. For example, in Taiwan governmental employees enjoy many benefits in term of healthcare, pensions, job security, but these

[78] According to current plans the vaccine center at CDC will not be fully integrated into NHRI's facilities located in Chunan before 2009. The facilities include a plant, which is under revision for cGMP approval. The center, which will be semi-governmental, is planned to develop vaccines for pandemic influenza, enterovirus 71, dengue virus, N. meningococcal and cell-culture-based Japanese encephalitis virus. In the plan from 2008 the ambition was to start clinical trials for the EV71 vaccine, while for the JE vaccine, the target is to reach pre-clinical trial, and to find a strategic partner to continue the development. Also a flu vaccine is under initial testing (H5N1), the clinical trials are planned to start by 2009 (Interview, Pele Chong).

benefits do not apply to the employees of semi-governmental institutions (Interview, Pele Chong Interview, Lillian Wei).

Use not as straightforward as expected

As can be imagined, the government has dedicated a considerable amount of resources to building a national vaccine capacity. An infrastructure for the development and production of vaccines is emerging, but it has yet to reach the expected standards set by the government. In 2009 the NHRI facilities for vaccine production were still under construction, and the CDC had continued with the vaccine development at its facilities in Taipei. No move has been planned until the NHRI facilities are fully operational and cGMP approved. Like other governmental research institutes, the vaccine center will also have an open laboratory policy and assist universities and local biotechnology companies to produce GMP level vaccine candidates and to initiate phase 1 and 2 clinical trials in Taiwan and Asia. The main goal is to provide an infrastructure to conduct vaccine R&D primarily for local needs and to produce cGMP-approved vaccines for local use (Interview, Pele Chong; NHRI (2), Internet). Although the policy plan might seem quite straightforward (where development, production and use follow on from each other), the empirical material has so far illustrated quite a complex journey for both the vaccines and the industry.

In 2008 the management of the Japanese encephalitis vaccine was still in the hands of the vaccine center at CDC. It had passed the bio-safety testing and clinical trials were about to start. It has however been a slow process, in relation to the ambitions of Taiwanese policymakers who wanted a vaccine within a few years. As a result industry commentators as well as policymakers have seen the development as a disappointment (Interview, Pele Chong; Interview, Lillian Wei). The policy ambition to create a vaccine industry seems to have been even more complicated. For example, the Taiwanese government has had high expectations of being able to engage private and public sector actors in making Taiwan self-sufficient in influenza vaccines. A project to create a proper production structure for influenza vaccines named *Build, Own and Operate* (BOO) has been one of the Taiwanese government's most ambitious and costly undertakings in the vaccine endeavour so far. On 21 September, 2008, the following could be read in the *China Post*, a major Taiwanese newspaper, about the project:

> A build-own-operate (BOO) project to manufacture influenza vaccine has been called off after years of delays, delivering a setback to the country's ambitious plan to be the first developing country to build an independent and self-sufficient vaccine manufacturing capacity, a government and pharmaceutical industry source said last week

Although development and production of vaccines has not been on par with expectations, the using structure from the government perspective, on the other hand, is clear. As reported in the CDC annual report for 2007 (CDC, 2007: p35), the DoH had in 2003 approved CDC's plan to establish a medical network to prevent and control communicable diseases. A main component in this initiative has been to secure a supply of vaccines which can be distributed to this established network of healthcare resources. The network covers a large number of different actors all over Taiwan, as described by the CDC in the following quote.

> Taiwan CDC has established Infectious Disease Command Centers in each district of Taipei City, Northern, Central, Southern, Eastern Taiwan and Kaokaoping area. Each command center is made up of representatives of the local health bureaus, hospital superintendents and medical centers to be responsible for infectious disease control in their respective areas. (CDC, 2007: p12).

However, the plans of Taiwanese developers and producers might be different from those of the Taiwanese government. For instance, the NHRI is also considering other users of the vaccines which are currently under development. The intended user was initially the Taiwanese government. However, since the Taiwanese government has not been primarily concerned with the business aspect and funding problems, the director of NHRI's vaccine center gave the following statement on other planned users.

> The funding to vaccine projects have been reduced, and developing vaccines for sale in overseas markets, mainly other Asian countries, is seen as important for continued financing of the research center. As of now, the government gives directions and it will continue to do so in the future. However there will be more autonomy in the future due to the changed financial situation. (Interview, Pele Chong).

With the above quote, let us now sum up the main points of this chapter. This will be followed by the final empirical chapter, telling the story of the development, production and use of liposome-based drugs in Taiwan.

Summary

This case has shown how Taiwanese policy has tried to steer the development, production and use of vaccines. Although the government has supported actors from both the private and public sectors, the results have not been on par with expectations. Although a using structure has been present, there have been difficulties with creating development of vaccines and a production structure. In this chapter, the ambition to develop a vaccine industry has been exemplified specifically through the case of the development of a Japanese encephalitis vaccine. After a decade of trying to develop a Japanese encephalitis vaccine with a standard method, the project has systematically lagged behind the government's planning, showing the intricacies behind the interaction between development, production and use.

CHAPTER 7
LIPOSOME DRUGS IN TAIWAN

This chapter will focus on a particular area of biotechnology – liposomes – and how related biopharmaceutical drugs are developed, produced and used. Liposome technology and its application in drug-making were initially not considered by Taiwanese policymakers to be an interesting commercial area. In comparison with the previous case, the Taiwanese government has not been as proactive in the support of liposome drugs. The associated projects have, however, been embedded in a government-supported environment.

7.1 New opportunities in biopharmaceuticals in Taiwan

In Taiwan the government has, since it started promoting biotechnology, established three national research programs in the life sciences sector: Agricultural Biotechnology; Biotechnology and Pharmaceuticals and; Genomic Medicine. In the program for Biotechnology and Pharmaceuticals one of the main focus areas is the development of new drugs, including biopharmaceuticals. Since the Taiwanese government has specifically targeted this area in order to accelerate growth and development, companies involved in drug development are eligible for extensive support (MOEA, 2008a). As mentioned previously, in Taiwan companies involved in the discovery and development of novel drugs are still few in number. The Taiwanese pharmaceutical industry consists mostly of generic drug manufacturers catering predominantly to a domestic market supported by the national health insurance system, which reimburses patients for medicines[79]. The government has tried to reform this inefficient healthcare system, which has proven to be profitable for a large number of generic drug manufacturers but been a large burden on government finances (Cheng, 2003). As a result, the number of generic drug manufacturers has been decreasing lately. For example, in MOEA statistics from 2007 the number of pharmaceutical companies had declined from 419 in 2005 to 368 in 2006 (MOEA, 2008a).

[79] Taiwanese pharmaceuticals companies are often kept alive by their close relationships with hospitals, in turn supported by the policies of the Bureau of National Health Insurance (BNHI). Taiwan has a national health insurance system that reimburses patients, a system that has been under much controversy (Biotech East (2), Internet; Cheng, 2003).

The government efforts to control its budget for reimbursement of drugs (mainly generic) and its increased support to biopharmaceutical companies, has improved the situation for the conduct of novel drug discovery and R&D in Taiwan. There has been a growing but still small number of research-based pharmaceutical and biotechnology companies developing novel drugs, or at least modifying existing drugs for new uses. In order to increase biotechnology activity, there have also been incentives for the pharmaceutical companies to move into the field of biopharmaceuticals (Biotech East, (2), Internet). However in areas such as drug discovery and development, the time horizon to extract any commercial value is usually very long, requiring extensive interaction between development, production and use. Biopharmaceutical development is also subject to strict regulations due, for example, to the ethical dimension in biotechnology R&D (Interview, Herbert Wu). To create novel drugs with a clinical advantage over existing drugs has thus been a complicated task for companies all over the world, and not least for Taiwanese companies. As of 2008 no Taiwanese company had yet at its own capacity developed and produced a novel drug (Interview, Julie Sun; Interview, Wu Rong Tsun). A number of companies in Taiwan are working towards this goal, however, and one of these is Taiwan Liposome Company (TLC) that develops liposome-based biopharmaceutical drugs. In the next section we will look more closely at the development, production and use of liposome drugs in Taiwan.

Liposome based drugs - Science and Business

Liposomes are tiny bubbles (vesicles) made out of the same material as a cell membrane. An important property of liposomes is their natural ability to target cancer and therefore they have been used to mainly deliver drugs against cancer. The early scientific discoveries and progress of liposome research were made at Cambridge, England, where Bangham, Standish & Watkins (1965) first described the small vesicles. Later on in the 1970s, considerable scientific contributions were made at the University of San Francisco. It was also in the early 1970s which liposomes were first used as systems for drug delivery[80] (Liposome evolution, Internet). Although the idea of using liposomes for drug delivery had existed since the early 1970s there were several problems that made its clinical application difficult. For example, a major problem was that the body broke down the vesicles before they reached the target site,

[80] I.e. systems for the delivery of drugs to target sites of pharmacological actions, technologies employed include those concerning drug preparation, route of administration, site targeting, metabolism, and toxicity.

since they were seen by the immune system as foreign bodies. This obstacle, among others needed to be resolved before liposomes could be effectively used for drug delivery (Interview, Yun Long Tseng; Haumann, 1995).

Due to the complications only a handful of attempts were made towards finding commercial applications. More dedicated attempts to commercial activities began in the early 1980s with three US based companies: The Liposome Company; Nexus; and Sequus. All three companies were successful in solving the problem with the short life of liposomes in the human body. Based on these advances the three US based companies could eventually develop liposome drugs. Three decades after the initial discovery of liposomes, a handful of liposome drugs were available on the market: Sequus with Doxil; The Liposome Company with Abelcet and; Nexstar with Ambisome. Among these, Sequus's Doxil had the better success on the market (TLC, 2006).

Doxil was approved by the FDA for treating ovarian cancer[81], breast cancer and Kaposi's sarcoma[82]. It was based on Doxorubicin, an off-patent chemotherapeutic drug treating several forms of cancer[83] that became available in the mid-1980s. Like all chemotherapeutic drugs, Doxorubicin had some severe side effects including nausea, hair-loss, and in general weakened the immune system. The most dangerous side effect was however the increased risk of heart damage, which rose proportionally to the amount of the drug taken. This severe side effect limited the amount that patients could take, and thus also affected the therapeutic value of the drug. This problem with Doxorubicin made it suitable as a derivative[84] for liposome delivery. What Sequus formulated was a liposome encapsulation that significantly prolonged the drug's circulation in the bloodstream as well as decreasing the side effects (Doxil, Internet). For instance as described in the *Annals of Oncology*, Doxil (PLD) had considerably fewer side effects in treatment for metastatic breast cancer (MBC):

> In first-line therapy for MBC, PLD provides comparable efficacy to doxorubicin, with significantly reduced cardiotoxicity, myelosuppression, vomiting and alopecia (O'Brian et al., 2004:p.440).

[81] Ovarian cancer is cancer that begins in the cells that constitute the ovaries, including surface epithelial cells, germ cells, and the sex cord-stromal cells.
[82] Kaposi's sarcoma is a type of cancer.
[83] Doxorubicin is widely used to treat cancers including, breast, ovarian, bladder and lung cancer.
[84] A derivate is a drug which is off patent (not protected by intellectual property rights) acting as an underlying drug for in this case a drug delivery encapsulation

The successful launch of a liposome drug on the market eventually led to Sequus being acquired by the pharmaceutical company ALZA. Doxil later became one of ALZA's flagship brands with sales reaching 100 million US Dollars in 2001. Today there are a handful of companies involved in the R&D of liposome based drugs and a few liposome applications are available for clinical use (TLC, 2006). Table 7.1 below shows an overview of the major companies, including existing products and development pipelines.

Table 7.1: Major liposome companies (2007)

Company	**Products on the market**	**Pipeline**
Gilead (formerly Nexstar), US	1. Ambisome 2. Daunoxome	No current drug pipeline
Johnson and Johnson/Alza (formerly Sequus), US	1. Doxil 2. Amphotec	1. Anti HER2 Doxil (pre clinical)
Elan (formerly The Liposome company), US	1. Abelcet 2. Myocet (approved in Europe)	1. ELL ELC 12 2. Bromotaxane
Inex, US	No products on the market	1. Onco TCS (phase 3 clinical trials) 2. Vinorelbine (entering pre clinical)
Taiwan Liposome Company, Taiwan	1. Lipo Dox (approved in Taiwan)	1. Lipo AB 2. Nano VNB 3. TLC X88

Source: (TLC, 2006)

As the table shows, nearly all the companies are based in the US, predominantly on the West Coast. The exception is Taiwan Liposome Company (TLC), which has its headquarters in Taiwan. The company however has a US subsidiary in San Francisco where much of the R&D is conducted. The drugs that have been developed or are in the development pipeline are mostly targeting cancer, where liposome drugs have been shown to have the most promising effects. Currently there are two application areas for liposome drug delivery. The two kinds of liposome drugs are: The first group *Dox* that treats cancer and the second group *Ento B* that are anti fungal. In the next section I will portray the development, production and use of liposome based drugs in Taiwan.

7.2 Taiwan Liposome Company: Developing liposome drugs in Taiwan

In comparison to the Japanese encephalitis vaccine project, the development of liposome drugs in Taiwan has not been policy directed. It has mainly been lead by TLC, a biopharmaceutical company engaging in R&D and commercialization of proprietary drug delivery systems for treatment of cancer and infectious diseases. The company was founded in 1997 by Dr Keelung Hong, who wanted to create a company developing drugs by using liposome technology. TLC had in 2008, 60 employees and the head-office is located in the Nankang business park in Taipei, the company also has a subsidiary in San Francisco. After 10 years of existence, the company has one drug available in the Taiwanese market and four drugs are in the product pipeline (Interview, George Yeh). In the table below, the drugs that are currently being developed are shown.

Table 7.2: Product pipeline, Taiwan Liposome Company (2008)

Product	Technology	Phase	Partnerships
Lipo Dox	Underlying drug: Doxorubicin. Liposome formulation developed by Keelung Hong	Out on market, approved for treatment of ovarian cancer and Kaposi's sarcoma by the DOH 2002. Sales of 90 million NTD (2004)	Licensed to TTY Pharmaceuticals for production and sales
Lipo AB	Underlying drug: Amphotericin B Liposome formulation developed by Keelung Hong	Clinical trials phase 2	Licensed to TTY Pharmaceuticals for production and sales
Nano VNB	Underlying drug: Vinorelbine NanoX, licensed from Hermes (Keelung Hong co-developer)	Clinical trials phase 1	Licensed to Nankuang Pharmaceuticals
TLC 188	Dual function technology, NCE California Pacific Medical Center owner of the patent (Yang)	Filed patent 2005, Filed for IND Q3, 2006. Currently in pre-clinical trials	No
TLC X88	Dual function technology, NCE Underlying drug: Camptosar: Camptothecin analogue, California Pacific Medical Center owner of the patent. (Yang)	Pre-clinical	No

Sources: (TLC, 2006; TLC (1), Internet)

The story of TLC however starts much earlier than 1997 when the company was formally established. The founder and CEO of TLC, Keelung Hong, had 30 years of research experience of cell membranes and liposome technology. In the late 1970s he joined the research team at the University of San Francisco Liposome Lab (USFLL) where a number of important discoveries of liposomes were made. After researching liposomes for over two decades, Hong was invited back to Taiwan in 1995 to conduct several seminars at National Taiwan University (NTU). This was done with grants from the Taiwanese government that had just started to promote biotechnology. At the time there were no novel drug discovery and development companies in Taiwan. Government officials were eager to import "foreign" technologies. Inviting overseas scientists to introduce novel technologies and scientific discoveries was however more of an academic activity than an industrial enterprise. Hong's role eventually became to instruct researchers at NTU about liposomes in order for them to later conduct their own scientific research and write academic papers. In the US he had several liposome patents to his name and also been involved in founding start-up companies. Therefore the idea of setting up a company in Taiwan was in the back of his mind. But it would be a risky business, even after 30 years of the technology's existence there were few companies specializing on liposomes, and there were even fewer liposome drugs on the market (TLC, 2006; Interview, Keelung Hong).

During a two year period Hong helped to create a research base and educate researchers about liposomes at NTU. With the new business opportunities arising from the government's efforts to support biotechnology, his idea of starting up a company was soon to be turned into reality. After two years of educating and training researchers at NTU, Hong decided in 1997 to form a company with some of the researchers he had advised. Since Hong did not have tenure at NTU or any other Taiwanese university he was not restricted by the regulations the government had set up concerning the involvement of university faculty in commercial activities. At the time there were only a handful of companies involved in drug development, not including the generic drug manufacturers, in Taiwan. The new company was named Taiwan Liposome Company and it was one of only a few Taiwanese biopharmaceutical companies. The strategy for TLC was to first develop a generic liposome drug. The liposome patent for which the first drug candidate was based on was co-owned by Hong and there were not any intellectual property conflicts as the intended project was to be developed for the Asian market only. The TLC team decided to develop a liposome formulation of Doxorubicin for the Taiwanese market as a first project (Interview, Keelung Hong; Interview, George Yeh).

As mentioned earlier there was already one liposome based Doxorubicin on the international market, Doxil, which was available in the US and Europe. A main reason why the same underlying drug was chosen was because Hong had been involved in the development of Doxil, thus he had some experience in developing this drug. TLC however wanted to use a new liposome encapsulation which Hong himself owned the patent to, making it slightly different from Doxil. In 1997 the research team at TLC started to perform the first tests at the Biochemistry Department at NTU under the supervision of Yun Long Tseng, a former research fellow at USFLL. The testing went smoothly and pre-clinical trials were started later that year, as well as initial preparations for clinical trials. Since the drug had not been approved in Taiwan or any other Asian country, a new set of clinical trials would have to be undertaken according to the standards established by the Department of Health and the Bureau of Pharmaceutical Affairs, the Taiwanese equivalent of the US FDA[85] (Interview, Yun Long Tseng).

No government support

With the development underway, start-up capital was needed in order to pursue the goal to put out a drug on the Taiwanese market. To finance the operations, the company applied for government funding. Even though the government was actively promoting the biotechnology industry, and there were a number of government grants set aside to help fund start-up companies, especially in drug development, TLC was not able to receive any government support. According to Hong, the following reasons were given for the rejection:

> The government did not believe we had enough potential and they said that the scale of our business was too small. The drug we wanted to develop was only considered a generic one, and Taiwan already had too many uncompetitive pharmaceutical companies manufacturing generic drugs. We were just not novel enough (Interview, Keelung Hong).

TLC also approached other financiers such as venture capital firms. At the time the Taiwanese venture capital industry was considered one of the most vibrant in Asia, with over 150 firms. The Taiwanese government was actively trying to get these firms involved in biotechnology.

[85] The US Food and Drug Administration is a government agency under the United States Department of Health and Human Services responsible for regulating and supervising the safety of for example foods, drugs, vaccines, biological medical products, medical devices et cetera.

However, Taiwanese venture capitalists were not particularly convinced by Taiwanese biotechnology businesses (TVCA, 2006; Interview, Chester Ho). In the case of TLC, the venture capitalists contacted were not willing to commit any funding as the company was considered too high risk (Interview, Hong). Considering the Taiwanese venture capital business model, this was not a surprise. Taiwanese venture capital investments were almost exclusively made in companies in the electronic and semiconductor sectors, especially in their expansion stages. Since these companies already had finished products out on the market they were considered less risky. Start-ups and early stage companies only received a very small fraction of investment[86]. Hence biotechnology was clearly not an area which evoked much interest of Taiwanese professional financiers. Why would they invest in biotechnology, where returns on investment were very far ahead in the future? Investing in semiconductor and electronic companies were generally safer (TVCA, 2006; Interview, Benjamin Jen).

To collaborate with local pharmaceutical companies was neither at this stage a viable option. TLC had just been formed and did not have any drug candidates in clinical trials. This would put the company in an inferior bargaining position. Furthermore, Taiwan's pharmaceutical companies were small in size and mostly involved in producing generic drugs. Therefore they could not really benefit early stage research-intensive companies (Biotech East (2), Internet; Interview, Su Yeu). Without support from the government, venture capital or pharmaceutical companies, TLC had to rely on other sources of funding. The company turned to business acquaintances, friends and family for loans and was able to raise 27 million NTD (roughly 1 million US Dollars). With this funding the development could continue and it gave TLC freedom to decide its own path without any interference from financiers on how to run the business (Interview, Keelung Hong).

The seed money would be enough to keep the company running for at least a few years. The aim was to push the drug candidate to at least clinical trials and find some partners for production, before another round of funding would be needed. To minimize costs, TLC initially stayed in the laboratory of the Department of Biochemistry at NTU. The company had been given access to the facilities for its development purposes and the researchers that Hong had advised for over two years were involved, which kept the costs low. For pre-clinical

[86] Traditionally Taiwanese venture capital firms have held the equity of invested companies until they exit with an IPO. With funds being terminated usually after 7-8 years, Taiwanese firms have therefore preferred to invest in late stage firms with already products proven in the market-place. Drug development if successful represented at least 8-12 years of commitment. Semiconductor technology on the other hand could be developed and commercialized in less than half that time.

research [87] there was no need for advanced equipment, and the NTU laboratory was sufficiently equipped. Since the drug was already out on the market in the US, TLC had access to existing test protocols, which made the work less time-consuming. However, in order to get a drug approved in a new market, all proper procedures and all stages needs to be performed again. The pre-clinical testing was done with a team of five researchers engaged in the project. It went as planned with promising results and within one year TLC had finished the testing. But to move into clinical testing the drug candidate needed first to obtain the approval of the authorities. TLC filed an Investigational New Drug (IND) application in 1998, and plans to proceed to clinical phase 1 were underway. TLC's limited resources nonetheless made it difficult to start clinical testing. Compared to pre-clinical testing, clinical trials would require much more capital and advanced equipment[88] (Interview, George Yeh).

The Taiwanese hospital system has traditionally had a positive view on conducting clinical testing and each major hospital in Taiwan have collaborations with research universities and pharmaceutical companies. The general attitude among Taiwanese patients has also been positive towards trying out of new drugs. Due to these circumstances, the Taiwanese government has actively promoted Taiwan as a center for human clinical testing in Asia. For clinical testing NTU Hospital, where Hong and his colleagues at TLC had some personal contacts, was contacted. The hospital was considered one of Taiwan top medical institutions and the administration was supportive to the testing of new drugs (Interview, Keelung Hong; Interview, Chen Chei Hsiang).

The phase 1 of clinical trials proceeded according to standard protocol without any major complications and included a handful of patients. The scale at this stage was manageable for TLC, even with the tight budget. For example, the amount of the active ingredient in the drug required at this stage was possible to produce at a laboratory-scale. However in order to move into phase 2, where sometimes hundreds of patients are involved, a much larger quantity of the drug would be necessary. Given TLC's resources at the time, it would not be enough to supply the amounts needed for phase 2 of clinical testing. The

[87] The purpose of pre clinical is to evaluate whether or not a drug candidate will be safe to test on human beings. For this purpose animals are used to test variables such as efficacy, dosage, side effects etc.

[88] The drug candidate is being tested on humans and the safety criteria need to be very high. If any major complications (for example if a test patient would suffer severe side effects or even die) were to occur it usually leads to the termination of the project and has severe consequences legally and financially for the company. Phase 1 clinical trials only require a handful of people, and the main motive is to evaluate and test the safety of the drug candidate. For this purpose usually healthy male volunteers are used, and it is very seldom that sick patients are in the first test groups. The tests need to be monitored by qualified personnel, and this can of course not be done in a university laboratory.

production would also have to satisfy strict sanitary requirements, in order to gain approval from the Department of Health. Hence a suitable partner was needed for scale-up production of the active ingredients as well as assistance with clinical testing (Interview, Yun Long Tseng).

Being an accomplished scientist, Hong had built up a network with other researchers and scientists. Nonetheless neither he nor anyone else in the company had any established connections with Taiwanese pharmaceutical companies. Neither did they know if there were any local pharmaceutical companies with facilities ready to produce liposomes. The development of TLC's drug candidate was thus temporarily halted in the absence of a producer of the active ingredient in the drug. TLC had at least achieved partial success by bringing forward the drug candidate to clinical trials, although it was still not available for Taiwanese patients. But in the process of conducting the first phase of clinical trials the company had gained some support. A few oncologists at NTU had followed the pre-clinical tests and were impressed with the phase 1 results. They wanted the drug to be available for the Taiwanese market and were willing to help find a producer of the drug candidate. Teaming up with the oncologists in a quest to find producers, TLC started contacting pharmaceutical companies capable of assisting with the scale-up production and clinical trials. Initially none of the companies contacted were interested, however after several attempts one company was interested, namely TTY Pharmaceuticals (nowadays TTY Biopharm, hereafter TTY) (Interview, Keelung Hong).

TTY had the capability of producing and distributing drugs. The company had been founded in 1960 and was one of Taiwan's largest pharmaceutical manufacturers[89]. Low profit-margins, including an excess of generic manufacturers in Taiwan, and competition from low cost generic drug producers in China and India, had led TTY to redirect its focus. The company wanted to move into drug development. An incentive partially came from the government, which had started to provide financial aid to companies wishing to commit to R&D intensive activities. The transformation into a more research oriented company was not effortless for TTY. First of all the company lacked not only experienced researchers, but also capital for drug development. This was partly solved by government support which funded TTY to engage in research intensive activities[90]. Later, a capital infusion from the stock-

[89] In 2002 TTY Pharmaceutical had 263 employees, with revenue of 36 million USD. In 2001 the company was listed on the Taiwan Stock Exchange (ISPE, internet).
[90] Roughly 10-15 percent of the total revenue is today re-invested into research and development. TTY has since then tried to establish itself as a pharmaceutical company which integrates drug development, manufacturing and sales.

market through an IPO in 2001 also gave TTY a broader financial base. With the ambition to place more emphasis on anti-cancer medical biotechnology TLC was a suitable partner for TTY. The focus was to concentrate on high incidence Chinese diseases, in particular the most prevalent forms of cancer in the Chinese population. Thus the timing was good for both companies, TLC wanted to move into clinical trials phase 2 and TTY wanted to direct attention to biopharmaceutical drugs. An agreement was reached where TLC's drug candidate, in phase 2, was to be transferred over to TTY. The drug named LipoDox® (short for liposome encapsulated Doxorubicin) and would be manufactured and marketed by TTY (TTY, Internet; Interview, George Yeh).

The purpose of clinical testing in phase 2 is to evaluate the toxicity and efficacy of the drug candidate and it is tested on a larger group of people, sometimes up to several hundred. Because of the larger pool of patients it is usually during this stage the indication of the drug candidate, i.e. what disease it will target, is decided. Since the underlying drug, Doxorubicin was used to treat several forms of cancer there was no reason to believe it would be different for LipoDox[91]. However, according to earlier experiences, liposome encapsulation would probably narrow down the application area. Nevertheless new indications could also be found and the old underlying drugs would get new properties with enhanced efficacy, giving the drugs novel characteristics (Clinical Trials, Internet; Interview, Keelung Hong).

With the partnership with TTY, phase 2 of clinical trials was conducted over a two year period. The tests that were done indicated that LipoDox similar to Doxil should be used to treat ovarian cancer. The results also showed that the drug candidate had higher efficacy than Doxorubicin. Soon thereafter the phase 3 of clinical trials was commenced. In 2002 this stage had been completed and TLC had with its partners managed to put the LipoDox through clinical trials. Later the same year the Department of Health approved LipoDox for treatment of ovarian cancer. As agreed, TTY would take care of the production, marketing and distribution of the drug (TTY, Internet; Interview, George Yeh). LipoDox was considered a big achievement, in less than 5 years the company had with the help of various academic and business partners been able to develop and produce a liposome-based drug in Taiwan.

[91] In the case of many cancer drugs, liposome encapsulation has proven efficient in reducing side effects and increasing efficacy in original cancer drugs. The common problem of existing cancer drugs is that they are highly toxic. The reason is that the drugs attack all cells, including healthy ones. The employment of liposome has increased the efficacy and decreased the common side effects of cancer drugs (e.g. nausea, fatigue and hair-loss).

However, was LipoDox a novel drug or generic? LipoDox had unique features and it was created by using a liposome formulation which had not earlier been combined with existing drugs (Interview, George Yeh). But what had been developed and produced was according to Taiwanese authorities a generic drug, since the derivate was an existing drug. Technically, it was not a novel drug based on a new compound and there was also already a similar liposome-drug on the US market. Regardless, although LipoDox exhibited some characteristics which made it to some extent unique it would not have been possible to get it approved as a novel drug in Taiwan (Interview, Yun Long Tseng). The quote below made by an executive at a drug development company explains the situation:

> The problem has had somewhat of a catch 22 character. No novel drugs had been approved in Taiwan as the CDE have no experience in approving novel drugs. There are also three different organizations which need to approve the same drug application. The regulatory system is therefore not streamlined and has caused much problem for drug development companies. In Taiwan drugs are approved by the Department of Health, the bureaucrats have experience in handling applications of generics drugs and the decision process highly efficiently. For novel drugs, there is a major bottleneck in terms of in-experienced reviewers. The lack of qualified professionals is also troubled by a regulatory framework which is not streamlined and up to now no new drugs have been approved in Taiwan (Interview, Hubert Hu).

Nonetheless novel or not, what was more important for TLC was that the company had managed to develop a product in Taiwan, and it served as a learning experience for future projects.

The development of more drugs

TLC had achieved the goal of developing and producing a liposome drug in Taiwan. For Hong this had been the primary goal, and the company now had an important choice to make. The company had no representative office or a professional management structure. What it had was a tangible product, competent researchers and a network of partners in development and production. If TLC decided to continue the business it was now easier to get funding, but the company would need to recruit an experienced business manager. After discussions of how the company should continue, two alternatives were presented. The first alternative was

to discontinue the business and collect royalty from licensing out LipoDox. The sales figures of LipoDox were seemingly stable and a prognosis showed that the investors' money would be returned within two years. The second alternative was to scale up the business and continue to develop new drugs. Behind this aim was the fact that there were no companies in Taiwan that had yet to be successful in developing novel drugs. The large majority of Taiwanese pharmaceutical industry was manufacturing generic drugs and the few attempts made at developing novel drugs were at a very early stage. The government's support programs to biotechnology had functioned as a catalyst for the emergence of a small but increasing number of companies involved in biopharmaceuticals. However, many of them were struggling and experiencing the challenges of novel drug discovery and development (Interview, Keelung Hong; Interview Yun Long Tseng). With the lack of viable biotechnology businesses, the Taiwanese government had in 2002 started to put more emphasis on creating spin-offs from the research institutes, an old policy originating already in the 1970s (Cyranoski, 2003). The research institutes were however under heavy criticism. For example DCB had existed for 20 years, but in terms of producing useful technologies and products for the industry the results were modest to say the least (Harris, 2002).

The research team at TLC, with Tseng as R&D director, saw the above factors as a motivation to continue with the business plans. The ambition for TLC was to prove that it was possible to develop novel drugs in Taiwan. Of course the management of the company was aware of the difficulties accomplishing such a feat and did not expect to bring a novel drug to the market alone, or within the near future. The plan was to continue cooperating with research intensive organizations in early R&D and with local pharmaceutical companies in later stage clinical development and product marketing. In this way it was believed that the cost levels could be kept low and the development times reduced. To maintain the business, TLC would also have to make the company more formal and business oriented to be able to attract funding, even though focus would still be on R&D. For this purpose the company needed a business manager[92] (Interview, Keelung Hong; Interview, George Yeh).

In 2002 George Yeh joined TLC as the general manager. Hong and Yeh already knew each other as they had met when Hong was giving a speech on Chinese history at University of California, Berkley a few years earlier. After graduating from business school in the US,

[92] It is no accident that private sector firms have taken the lead in drug development. Huge sums of money are required to develop a drug with fast burn rates. Furthermore, the development of new drugs takes between 8-12 years. Usually no academic institution has the capability of bringing a product to the market. Even though the academic institutions preside over the large quantity of the brain-power which makes big contributions to science, the drug development process comprises very much more than pure research.

Yeh had worked with fund management and finding investments to high-tech businesses. He had also worked as CFO of Hermes Biosciences, of which Hong was a co-founder. There Yeh had helped to structure and negotiate technology transfers and license contracts with pharmaceutical companies. Initially Hong had asked Yeh to help him find a manager but after some discussion Yeh was interested in the job himself. A vision for TLC was to be a successful example for the Taiwanese biotechnology industry to follow. (TLC (2), Internet; Interview, George Yeh)

One of the first tasks for Yeh was to raise more money. As mentioned, TLC had earlier had funding problems. The government, pharmaceutical companies and venture capital firms had been reluctant to invest. However after successfully developing a drug and out-licensing it, TLC now believed it would be easier to attract the interest of investors. The company was starting to get recognized in Taiwan and was for example given the "high-tech entrepreneur of the year" award by the MOEA in 2002. Thus TLC applied for government funding a second time and through negotiations over several weeks the government decided to not support TLC. A reason given was that the company needed no help from the government because it had already proven it could survive without public funding (Interview, Keelung Hong). Nonetheless there were several companies and venture capitalists that were interested in investing in TLC, but finding the suitable partner was not that easy, as the general manager elaborates:

> Government support can mean a lot of hassle, they will tell you what to do and your independence can be greatly affected. Funding is an intricate issue and finding a suitable investor is not just about accepting money from anyone. Pharmaceutical companies for example can be a good choice if you want to develop a technology, because this will benefit their own research and development. Venture capital on the other hand usually stresses the time factor and this can be quite bad for the technology development. Angel investors and friends worked for TLC the first time, but with their often limited capital, it might be difficult with a second round of financing. Funding is very much the issue about finding partners which can support your business idea and you need to clearly know what you want (Interview, George Yeh).

In 2002 TLC came through a second round of funding. This time the money raised was 50 million NTD (1.5 million USD) and the main sponsor was TTY. The new inflow of money allowed TLC to expand operations. Even though the government did not support TLC

financially, it offered assistance in other ways. After negotiations with the MOEA, TLC relocated to the incubation center at Nankang Software Park[93] (Interview, George Yeh). The Nankang Software Park became operational in 2003 and was an important part of the policy infrastructure to support the *Challenge 2008 development plan* and the *Two Trillion Twin Star Plan* (Nankang Software Park, Internet).

In the Nankang Software Park, three knowledge intensive areas were in focus: IC design; Digital content industry and; Biotechnology. The biotechnology zone at the Software Park had several research facilities and an incubation center that could host up to 18 biotechnology companies. Technically TLC was not considered a start-up company according to the definition used by the incubation center. However, after a series of negotiations with officials from the Nankang Software Park and the MOEA, TLC was given permission to locate to the incubation center. The general screening process for acceptance into the incubator center was performed by a committee consisting of representatives from academia, government and industry. The decision was based on a variety of factors, such as technology, business plan, revenues, human resources, and commercialization potential. The companies hosted at the incubator center would benefit from various tax incentives, low rent, help to write business plans, access to research facilities and so forth (Interview, Shang Pwu Shia).

TLC moved into the incubation center in 2003 and it was a step towards expanding the business. The company was still concentrating on R&D but had outgrown the university laboratories and therefore needed more advanced research facilities. The relocation to the Nankang Software Park was therefore necessary in order to grow the business and developing new drugs. With LipoDox, TLC was receiving revenue from the licensing fee but the income was not enough to support the ongoing R&D and business activities. Before relocating to Nankang Software Park, TLC had commenced the pre-clinical testing of Lipo-AB®. The liposome formulation applied on Doxorubicin was to be combined with a drug called Amphotericin B, an approved antifungal drug used to combat a broad variety of fungal infections. Since the drug was known for serious side effects, it was a suitable candidate for liposomal encapsulation. The clinical trials of Lipo-AB began in 2002, and the results showed that the liposomal formulation of Amphotericin had reduced toxicities and allowed patients to receive higher and more effective doses of the drug. For scale-up production and marketing

[93] The Nankang Software Park located in Nankang outside of Taipei is one of the newest establishments to the Taiwanese biotechnology and IC industry organization. The business/science park incorporates units both from academia, science and industry including big multinational corporations, start-up companies, governmental incubator centres and agencies. For example BPIPO, DCB, Academia Sinica, Philips etc all share the same address.

TLC had come to an agreement with TTY for a technology transfer. As in the case of LipoDox, TTY would out-license the rights to the drug at the start of phase 2 of clinical trials (TLC, 2006; Interview, George Yeh).

The development within the field of drug delivery, led by US-based companies, had by the late 1990s moved more towards technology differentiation and product orientation. It was becoming increasingly difficult for drug delivery companies to solely rely on single technology platforms. A clear trend was that more drug delivery companies were trying to develop or acquire multiple technology platforms in order to have more possibilities of developing drugs. (TLC, 2006) This was also the strategy that TLC was pursuing. The company's focus was to develop drugs based on proprietary drug delivery systems, and to this end the company had continued to search for partnerships with research intensive companies. This was mainly done in the US, since no Taiwanese company had any extensive experience of drug delivery systems. Moreover the help offered from the incubation center and the government research institutes was at this stage limited. The only research institute which TLC had any negotiations with was the DCB, but nothing substantial in terms of collaboration had been started, aside for some of the clinical testing (Interview, Yun Long Tseng).

The relationship between DCB and TLC exemplifies the difficulty of establishing interaction between research institutes and companies. Even though the DCB had existed for over two decades, the center had not accomplished anything major in the drug development area (such as discovering new compounds or developing any new drugs). The government's ambition to make the research center the main hub in helping biotechnology companies to grow, through for instance technology transfer, assistance in research among other services was also considered a failure. With this image discussions on discontinuing the operations had been held in policy circles (Harris, 2002). On the bright side, however, the center had researchers that were proficient users of technical machines and experienced clinical trials personnel (Interview, Lillian Wei).

New technology platforms

The main technology partners for TLC were to be found in the US. The choice of turning to the US was natural since the company's management already had established relationships with both business and scientific units. For example, Yeh had worked with several high-tech ventures in the San Francisco Bay area before joining TLC. Hong had spent most of his

academic career in the US, and in 1998 he had co-founded Hermes Biosciences, a company developing targeted drug delivery technologies. Hermes Biosciences located in San Francisco was a research-oriented company aimed at developing proprietary drug delivery technology. TLC licensed the rights to use Hermes technology in Asia for its new drug pipeline (Hermes Biosciences (1), Internet; Interview, Ching Chih Tsai).

The proprietary technology platform licensed was called NanoX®, and had been co-patented by Hong. It was possible to combine it with both existing chemotherapeutic drugs as well as new chemical compounds. An improvement, compared to earlier liposome formulations was that it offered a simplified manufacturing process for liposome drugs. The technology was also argued to provide significant and greater benefits than available therapies, such as improved efficacy and tolerability (TLC, 2006). With the use of NanoX the following drug candidate was named NanoVNB. The underlying drug was Vinorelbine, an off-patent chemotherapeutic drug, used in the treatment of breast cancer and lung cancer. The pre-clinical studies started in 2003 and were conducted at the new facilities in the Nankang incubation center. In 2004 the drug candidate was ready for clinical trials phase 1. The results showed that the encapsulation of NanoX liposomal delivery technology demonstrated better results for different tumour types, including breast, colon and lung cancer (Hermes Biosciences (2), Internet).

TLC's management decided that the new drug would be out-licensed to another producer than TTY. No disagreement between the parties had preceded this decision rather the basis for this decision was, as mentioned by TLC's general manager, the following:

> The reason was to diversify risk and increase our bargaining power. It is not good to be too reliant on only one manufacturer. Furthermore the production facilities of TTY were not suitable to manufacture using this technology (Nano X) (Interview, George Yeh).

The relationship and collaboration with TTY was still ongoing. In 2005 the sales of LipoDox in Taiwan had amounted to 160 million NT Dollars (roughly 5 million US Dollars) compared to 90 millions in 2004. TTY had also larger ambitions for LipoDox and efforts to market the drug in overseas markets were in progress. The company was already selling the drug in Thailand, and there were also plans to have the drug approved for distribution in China, Malaysia, Philippines, Egypt and Jordan. Furthermore, new clinical trials had been undertaken in Taiwan to find new indications. In 2004 the drug reached phase 2 of clinical testing for two

other cancer forms, advanced breast cancer and cutaneous T-cell lymphoma[94]. (TTY, Internet) A study of LipoDox at Taipei Veterans Hospital (Chao et al., 2003: p837) made the following comments on the drug's applicability to breast cancer:

> In conclusion, Lipo-Dox is shown by this first reported pilot study to be an active agent for treatment of advanced breast cancer with a safety profile that differs markedly from free doxorubicin. The dosage of 45-60 mg/m2 every 4 weeks was well tolerated. Because myelosuppression and other nonhematological toxicities associated with Lipo-Dox were generally mild and acceptable, further assessment of this drug particularly in combination with other chemotherapeutic drugs in the management of early or advanced breast cancer is suggested.

TLC had by early 2004 started negotiations with another pharmaceutical company, NanKuang Pharmaceutical Company (NanKuang). The negotiations were concerning the scale-up manufacturing and a possible technology transfer of NanoVNB. NanKuang founded in 1962 was a stock market listed company and a leading producer of injectables in Taiwan. The company, with clients from the US, Europe and Asia, had advanced production facilities, and a large part of the revenues came from its contract manufacturing operations (NanKuang Pharmaceutical, Internet; Interview, Yun Long Tseng).

A novel drug pipeline

In 2004 TLC came through a third round of financing. This time the money raised was 159 million NTD (roughly 5 million USD) and the main investors were NanKuang and Power World Capital Management (PWCM), a Taiwanese venture capital firm. The funding was to be used to broaden TLC's development direction. A trend among drug delivery companies was to apply their technologies in earlier stages of drug development. Alza for example, the company that acquired Sequus, had become involved with drug development at the discovery phase. The company was working with new molecular entities to which novel drug delivery technologies could be applied and TLC was also interested in moving towards this field. In 2005 TLC filed two new patents which would serve as a foundation for a new line of novel drug candidates (TLC, 2006; Interview George Yeh).

[94] CTCL is a slow growing form of cancer in which some of the body's white blood cells become malignant. These abnormal cells are drawn to the skin and some are deposited there.

The two patents had originally been developed at California Pacific Medical Center (CPMC) from discoveries made by Li Xi Yang, the Director of Radiation Biology and Radiation Oncology at CPMC. Yang was a former professor at Florida State University, with extensive experience in cancer research. His research was concentrated on radio-sensitizers and targeted modification of chemotherapeutics. At CPMC, Yang was conducting research on analogues to Camptothecin[95], a group of compounds which were considered highly promising to use in cancer drugs. The drug candidates based on these compounds had shown to have a higher anticancer activity compared to other drugs at similar stage of development (CPMC, Internet; Interview, Keelung Hong).

The active substance in Camptothecin had already been tried on incurable cancer patients in the 1970s[96], but had been too toxic to be of any clinical use[97]. Thus some derivates of Camptothecin were developed, and in the mid 1990s the first chemotherapeutic drugs based on this compound were approved. These were however still associated with heavy side-effects. Yang had on the other hand been able to change the chemical structure of Camptothecin, making it less toxic. He also added radio-sensitizers[98] to the new compound and was working to combine the conventional cancer treatments of chemo- and radiation-therapy into one treatment. This kind of research, although still at early stages, had been going on for several years at various places and Yang was a distinguished researcher within this field. In the in-vivo studies of his dual-function compound there had been some promising results, mainly high anti-tumour potency and lower levels of toxicity compared to the original drugs (TLC, 2006; Interview Keelung Hong).

How had this opportunity presented itself to TLC? Hong and Yang had earlier been colleagues at CPMC although not in the same laboratory. They knew about each others research and Yang had sought Hong for some advice on liposome encapsulation of the Camptothecin compound. This inquiry, lead to a collaborative project and eventually to the establishment of TLC Biopharmaceuticals, TLC's US subsidiary. The intellectual property

[95] Camptothecin is derived from the Chinese tree Camptotheca Acuminata and is an alkoid which is a member of a large group of chemicals. Some alkoids have been shown to be efficient in treating cancer. Camptothecin has been shown to have a unique ability to inhibit DNA Topoisomerase. By preventing DNA from replicating and ultimately cell death, Camptothecin has an anti-tumour and anti-leukaemic function (Hsiang et al. 1985; Pharmacology of Camptothecin, Internet).

[96] By physicians at the National Cancer Institute in Washington D.C.

[97] The problems with camptothecin had been the limited application in clinical therapies due to serious side effects (severe nausea, diarrhoea, and lowered white blood cell counts, as well as damaging bone marrow) and poor water-solubility. For this reason, Camptothecin based drugs are usually only prescribed when other treatments have failed.

[98] Radio-sensitizers are specific drugs that make cancer cells more sensitive to radiation therapy. Since radiation therapy also damages normal cells, it is desirable to find drugs that can either make a cancer tumour more sensitive to radiation without affecting healthy tissues, or that can shield normal cells from radiation.

rights to the Camptothecin analogue belonged to CPMC which had funded Yang's research. Since Yang in his capacity as the discoverer had the first rights to exclusively license it, he was made an offer to join TLC. With this arrangement, TLC was able to obtain the intellectual property rights to the Camptothecin compound. The cost was low, TLC agreed to pay CPMC a small up-front fee, and a percentage of sales of 1-2 percent (Interview, Keelung Hong). Because of the new opportunities presented, the management of TLC decided to establish a US subsidiary in San Francisco. TLC Biopharmaceuticals was founded in 2004 and Yang became the vice president. Two new drug candidates, TLC 188 and TLC 199 (the TLC X88 platform) based on the dual function compound became the first drugs in the development pipeline of TLC Biopharmaceuticals. The ambitions were high for the X88 platform since it included a compound and technology that had the potential of giving TLC its first novel drug. Hence TLC could become a major competitor to companies such as Alza and Gilead (Interview, George Yeh).

Tests on the new compound showed as expected that the side effects and toxicity were considerably lower with liposome encapsulation compared to without. TLC X88 would be a second generation of Camptothecin drugs aimed to overcome the problem of radiation- and chemo-resistance that was frequently encountered in clinical therapies. By combining liposome technology with radio-sensitizers and an anti-tumour compound the ambition was twofold. First that radiation-induced cancer cell killing would be enhanced and thereby substantially increase the local cancer control rate and; Second that the killing of cancer cells through chemotherapy and targeted delivery would result in a dramatic increase in the cancer cure rate (Interview, Yun Long Tseng). The first toxicity protocols as well as the clinical protocols were showing promising results. Animal testing had already been performed while screening the compound and pre-clinical trials were initiated in 2005. The tests that had been started at CPMC were moved to the new laboratories in the San Francisco subsidiary and an IND for TLC-X88 was filed in 2007[99]. In parallel with developing TLC-X88, TLC was also intending to continue its former business strategy of encapsulating existing drugs for which the patent protection had expired. The underlying drugs were the Camptothecin analogues: Camptosar developed by Pfizer & Pharmacia; Campto from Aventis, with a patent expiration

[99] In addition to developing a new drug, TLC is also planning the encapsulating of older Camptothecin based drugs.

in 2010 and; Hycamtin developed by Glaxo Smith Klein[100]. These three drugs were estimated to have a total market value of 1 billion US Dollars (TLC, 2006).

Combining two contexts

The advantages of having a company in two countries were that it would be easier to perform R&D and also less complicated to later apply for approval of the new drugs in the US and Taiwan. However, being in two countries meant that the expenses were now higher and a major concern was how to keep the costs down and utilize the advantages of the two environments. The US had a well developed infrastructure and regulatory system for drug development, in terms of biotechnology science and business the US was well ahead of most other countries. Taiwan, on the other hand had a nascent industry and under-developed supportive infrastructure. Even before establishing the US subsidiary, TLC frequently interacted with US-based companies, research organizations and researchers. The base of the company was however in Taiwan, where operating expenses were much lower. For example in Taiwan the company had been able to keep the costs down, through lower salary levels and low facility costs. Conducting clinical trials in Taiwan had also been favourable as patients were generally positive towards trying out new drugs and the government was strongly promoting the island as the clinical trials center for Asia. Taiwanese researchers compared to US researchers, nonetheless, lacked the experience in developing novel drugs and government bureaucrats had no experience in approving them (Interview, Keelung Hong).

TLC's plan was first to pursue clinical trials in Taiwan, taking advantage of the lower cost levels, later clinical trials would be conducted in the US. The main research and development activities would be performed in the US, where the experienced researchers could be found. It would also be easier to have a novel drug approved in the US than in Taiwan, due to the experience of FDA. The production of the drug and the active ingredients would be done back in Taiwan, through the established connections with Taiwanese

[100] Campothecin and its close chemical relatives (e.g Irinotecan and Topotecan) are the only known naturally occurring DNA topoisomerase inhibitors. They have been shown to have a higher anti cancer function than any other agent, and because of this unique characteristic these chemical compounds are also used in the newest chemotherapy drugs. Despite serious side effects with Camptothecin at present, some Camptothecin analogues, either semi-synthetic or synthetic based, have been applied successfully in cancer therapy, such as Topotecan (in 1996, the FDA approved Topotecan as a treatment for advanced ovarian cancers that have resisted other chemotherapy drugs, by GSK) and Irinotecan (in 1996, injectable Irinotecan was approved as a treatment for metastatic cancer of the colon or rectum; the drug is available under the generic name Irinotecan and is marketed by Pharmacia & Upjohn, now Pfizer, under the trade name Camptosar). Aventis later also launched a drug based on Topotecan, under the name Campto (TLC, 2006).

pharmaceutical companies. To finance these activities, TLC sought funding for the fourth time, and 15 million US Dollars were raised in 2008. With this money, TLC was pushing for two primary goals. The first goal was to prepare TLC X88 for clinical trials in Taiwan and later in the US. The development of the TLC X88 platform would mainly be conducted by the team at TLC Biopharmaceuticals. The second goal was to prepare for an Initial Public Offering (IPO) in the US. The clinical trial was planned to be a key milestone for TLC to put forward an Investigational New Drug Application (IND) and begin clinical trials in the US. The IPO plan was essentially a channel to attract further financing for additional product development (Interview, George Yeh).

A rigid using structure

The plan for the development of novel drugs through combining two contexts has been largely influenced by the existing resource structures and regulative factors. The incentives for companies to develop novel drugs in Taiwan have been few, from a regulatory perspective. As mentioned earlier, the Taiwanese authorities have not had the experience of evaluating and approving novel drugs all the way from pre-clinical to the conclusion with market approval. This can be exemplified with the time required to get a drug approved from the time clinical trials are finished. In Taiwan there is a lag of 30.5 months before a drug is approved for use, while in the US the corresponding amount of time is 5.6 months. Furthermore a minority of the new drugs that are introduced in Taiwan are of novel character. These novel drugs were exclusively imported and had been approved and clinically tested in other countries first (Huang, 2006).

Thus it is evident that there is a considerable bureaucracy, and getting novel drugs approved in Taiwan offers a substantial challenge. So far no novel drugs have been developed, gone though clinical trials and been approved in Taiwan. Instead most of Taiwan's pharmaceutical companies have relied on distributing and producing "me too" (generic) drugs. Developing these are less complicated due to the availability of existing protocols and evaluations, and for the authorities the process of approving generics is also quite streamlined. (Interview, Hubert Hu). But not only is generic drugs easier to approve and cheaper to develop, the national health insurance system in Taiwan has also benefited and made it profitable to produce generics through its reimbursement program of medicines (Cheng,

2003). This situation is for example commented on by the online service provider *Biotech East* which stated:

> No big name research-based drug or drug maker has emerged to date. Taiwan [has a] small market of only 23 million people, generic drug manufacturers [are] too many and too small compared to their counterparts in India and China, and a national health insurance system which while doing immense good for improving the health of the general population, has budget provisions which discourage the use—and therefore the development—of newer, more costly drugs (Biotech East (2), Internet).

Given the Taiwanese system, where hospitals have extensive business relationships with local pharmaceutical companies, producing generic drugs has been profitable, as is understood from the passage below:

> While more expensive drugs—particularly cancer drugs—produced by US, European and Japanese firms are not being paid for by the BNHI, hospital purchasing departments were buying cheaper drugs and being reimbursed by BNHI for more than what they paid. This is leading to over-prescribing; with drug prescribing becoming a profit center for a hospital. This may led to prescription decisions being based on profit instead of efficacy and value of the drug to the patient, according to the scheme's critics. It's been estimated that over US$600 million is lost annually in BNHI funds due to this payment reimbursement mechanism. Just where these funds get lost may explain how many small generics companies are still keeping their doors open, and why many of Taiwan's big hospitals are doing very well for themselves. (Biotech East (2), Internet).

With the incentive of generating a considerable income from generic drug-making, the costly and time-consuming process of developing novel drugs has not been that attractive in Taiwan, despite the obvious benefits. Novel drugs are rarely reimbursed by the national health insurance system and have been sold at a high premium, making it difficult for companies producing them to gain larger market shares (Interview, Wu Rong Tsun).

What has been suggested is that the using structure, including the networks of established actors such as hospitals, government agencies and generic drug producers, to a large degree dictates the development and production of biopharmaceutical drugs in Taiwan. Existing business relationships between policy, pharmaceutical companies, and hospitals create resistance to the use of novel drugs developed outside established networks. The use of

new drugs is also dependent on a larger structure of physical resources, as suggested by the quote below:

> Pharmaceutical drugs are one part of the treatment of cancer, other therapies are radiation, or surgery. Often a combination of these therapies is used, sometimes together or at different stages. Each one of these treatments have its benefits but also limitations. Drugs for example, usually have strong side-effects, such as hair-loss and nausea. Therefore there will always be alternatives. (Interview, Wu Rong Tsun).

Hence, drugs are one part of the treatment of cancer. It means that it they embedded in a larger portfolio of different alternatives, of which some have a considerable overhead, such as radiation machines. Even if a new drug with greatly enhanced clinical features is developed, it will still probably not be the only line of defence against cancer. In this respect, the fit of various solutions is a matter which the using structure strongly takes into consideration.

Summary

This chapter has followed the development of liposome-based biopharmaceutical drugs in Taiwan, where a main actor in the development has been Taiwan Liposome Company. The original discovery of liposomes was made in the 1960s, in England. However it was not until the 1990s that the first commercial solutions emerged. It was US-based companies that took the lead in development of liposome-based drug delivery systems. In Taiwan, TLC started its business activities in 1997, but the founder had already been involved with liposome related science and business for over two decades. Initially, government policymakers decided that liposome drugs were not a commercial area necessary to invest in because the activities were not sufficiently novel. Although since then several liposome drugs have been developed and produced, and lately a drug platform with novel characteristics has been established. What this case shows is that these processes have been reaching back far earlier than 1997 when the company was formed. Some of the characteristics that enabled the development of biopharmaceutical drugs were for example that TLC was able to connect to both established user and producer structures, in Taiwan as well as abroad. In the analysis in the next chapter these special characteristics will be discussed in greater detail.

CHAPTER 8
ANALYSIS

In the empirical chapters the emergence of industries and innovations related to semiconductors and biotechnology in Taiwan has been portrayed. An account of the emergence of the Taiwanese semiconductor industry, followed by a policy interpretation of the processes through which development, production and use came about was presented in chapter 4. The Taiwanese policy interpretation, which has garnered a development template of how to create new industries, was thereafter exemplified through its application to biotechnology. A general account of the development of the Taiwanese biotechnology industry, including the government's development plans, was the focus of chapter 5. To give a perspective of what happens under the surface of the hyped biotechnology industry in Taiwan, two case studies were thereafter presented, one related to a vaccine for Japanese encephalitis (chapter 6) and the other related to liposome-based drugs (chapter 7). It is now time to begin the analysis and discuss the findings. The analysis is divided into three main parts, with a total of five different sections. The structure of this chapter is as follows:

The first part (section 8.1) summarizes how government policy has viewed development, production and use in both the Taiwanese semiconductor and biotechnology industries, including a discussion of how the policy's expectations have not been fulfilled. In the next part, these identified challenges will be investigated more closely from a different perspective. The second part uses the analytical framework from chapter 2.2 and discusses from a resource interaction perspective how development, production and use emerged in the semiconductor, vaccine and liposome cases respectively (sections 8.2–8.4). Viewing from the resource interaction perspective will provide an increased understanding of the empirical problem raised in the introductory chapter, by providing a complementary empirically-based view. In the last part of this chapter (section 8.5), the lessons learned from the resource interaction perspective are summarized and contrasted with the policy understanding.

8.1 A policy-model to create new industries and the development, production and use of innovations

A policy understanding of how development, production and use of innovations occur and industries emerge are summarized in this section. The discussion is based on the descriptions of the visions of Taiwanese policy and its industrial and innovation policies provided in chapters 4.2 (semiconductors) and 5.1 (biotechnology). This section is structured as follows: First, the main components of the "semiconductor model" are discussed; Second, how a similar template has been applied to build up a biotechnology industry is summarized and; Third, the challenges with the Taiwanese industrial and innovation model are identified, including the expectations which have accompanied it.

Semiconductors

In chapter 4.2 the interpretation of the semiconductor industry as a creation of government policy was outlined. The focus of the description was based on research institutes sourcing and developing technology to transfer it thereafter to the industry through spin-offs. Universities, and local companies as well as foreign ones, were viewed by the Taiwanese government as less influential in the emergence of the semiconductor industry. The main components of the model formulated by Taiwanese policymakers were the following:

1. The government identifies market needs and the necessary technologies to create an industry.
2. Research institutes source/acquire technologies from abroad and develop them in-house.
3. The technologies from research institutes are transferred to existing companies or spin-off companies are created from the development projects.
4. Government provides support by building up infrastructure, providing investment incentives et cetera.

The model on which the Taiwanese government bases its current industrial and innovation policies is commonly referred to as *technology push*. More specifically, the policies are founded on an understanding that the emergence and growth of the semiconductor industry

was a result of a unidirectional linear model, based on four subsequent and clearly separated stages (see chapter 4.2): Identifying technological areas → Technology acquisition → Development of technology and transfer → Build permanent infrastructure. All stages are under the control of the government, including the creation of public organizations to develop one or more of these stages. In the policy view, the developing structure consists of "upstream actors", such as the research institutes. The producing structure is made up of downstream actors, such as local companies. The using structure is, for example made up of multinational companies and, is not explicitly discussed in government plans. The (business) users are largely assumed to be readily available to absorb any new solutions developed and produced and are not actively involved in the development. Furthermore an important component of this model is that it is based on imitation and upgrading of technologies where the government is the main actor in coordinating developing and producing activities.

Biotechnology

In chapter 5.1 the application of the "semiconductor model" to biotechnology was exemplified. While the template has not been applied strictly it has set the expectations and guidelines for innovation and industrial development in Taiwan. A distinguishable difference, however, is that in the Taiwanese government biotechnology plans it has been clearly emphasized that the Taiwanese industry needs to be more innovative and develop its own technologies, rather than to imitate existing technical solutions from abroad. The government rhetoric and support for this strategy has been strongly influenced by research on innovation systems and the knowledge-based economy. In this context the Taiwanese policy ambition to create a knowledge economy and innovation, has not been particularly different from what other governments in the developed world have expressed. Ideas of creating economic growth out of new scientific knowledge have been strongly promoted by the OECD for the past two decades. For example, as expressed in *new growth theory* the shift to knowledge-intensive sectors is considered the next step on the economic development ladder for advanced economies (see appendix 1).

As has been discussed earlier, the influences from the semiconductor industry interwoven in a discourse on the new knowledge-based development can be clearly observed in government policies directing the emergence of new science-based industries. What was described was an approach aimed at developing structures that can provide radical

innovations. These innovations are supposed to be transferred through having a proper production structure which is built up by the exercise of government policy. Use, on the other hand, is not explicitly an area of concern in Taiwanese biotechnology plans, but rather it is treated an exogenous factor, i.e., users are considered as given, and ready to absorb whatever is produced.

Summing up the findings hitherto it can be understood that with biotechnology there is a much stronger policy focus on science, hence a strong promotion of university research, which was absent from the semiconductor model. The government policies also illustrate that there is a strong focus on developing novel technologies for production and use. A mature technology would in this context be less preferable and garner less government attention. The government decides on which areas to concentrate, both scientific and business-related. Simply described, the Taiwanese development model attempts to apply in an accelerated way a linear model: Basic research→Develop technology→Launch/use related products. This model is implemented by the government through direct support to three sectors; "upstream", "midstream" and "downstream". These sectors all have their specific roles in the development of biotechnology. The upstream actors are expected to conduct basic research; the midstream organizations are involved with applied research; and the downstream actors are to commercialize technologies and products which they have developed or acquired from midstream.

Thus the idea of Taiwanese policy is to promote innovation in all sectors, ranging from upstream to midstream and to downstream. Technology transfer is the main mechanism for value creation. For this purpose the Taiwanese government has taken a pro-active role and assigned research institutes the role as hubs for technology development, production and transfer efforts. That is to say, spin-offs from research institutes are a preferred option to transfer technology and are viewed as an ideal way to directly exploit academic research. Furthermore existing companies are invited to diversify into biotechnology and collaborate with universities and research institutes. To support these general transfer mechanisms the government is responsible for building up the supportive infrastructure.

Emerging developing and producing structures with weak connections to using structures

Through the above discussion it is apparent that contemporary Taiwanese industrial and innovation policies have strongly emphasized three kinds of measures: First, the search for novelty; Second, the transfer of research results from science to industry, where users are considered already existing and; Third, the agglomeration of companies, research institutes and academia for a swift emergence of innovations and industries. Through these measures the Taiwanese government has claimed its success in some areas, such as increasing the number of companies (including start-ups), patents, academia-industry collaboration and publications in recognized scientific journals (i.e. direct measures). But even with these results the Taiwanese biotechnology industry seems to have been a disappointment to many commentators, as was demonstrated in chapter 5.2. Whilst policy plans dictate what research areas the "upstream" sector should be engaged in, what kind of technologies should be produced and what kind of "downstream" level companies to support, it is acknowledged that there is a knowledge bottleneck. As has been illustrated in the empirical material, there is a general sentiment that the Taiwanese biotechnology industry is a "failure", due to the modest revenues generated. However, as the empirical material suggested, could the perceived failure not rather be a symptom of unrealistic expectations, based on a model, that are difficult to fulfil?

To investigate this idea chapter 5.2 gave a deeper view, which transcended beyond "superficial" indicators such as number of academic publications and citations, patents, academia-industry collaborations, and new companies. Illustrated was a more intricate picture of innovation and industrial development. What was portrayed was that biotechnology in Taiwan is very much a government business. Through direct support the government has been able to increase academic research, and to build up a producing structure of research institutes and domestic companies. For example, through the perspective of the world-wide supplier of biotechnology equipment, GE Healthcare, it was illustrated that there is a growing academic biotechnology research and policy-supported research sector in Taiwan. The enlargement of these sectors has generated more business for GE Healthcare. In addition a larger number of companies have entered into biotechnology. What was obvious however is that the producing structure is still quite weak (in terms of number of projects et cetera) and more importantly connections to using structures are weak. This has resulted in many nascent biotechnology

companies with very uncertain future in Taiwan and which rely on government funding as a lifeline. A large problem is that once this support is withdrawn a majority of Taiwanese biotechnology companies would have to cease operations.

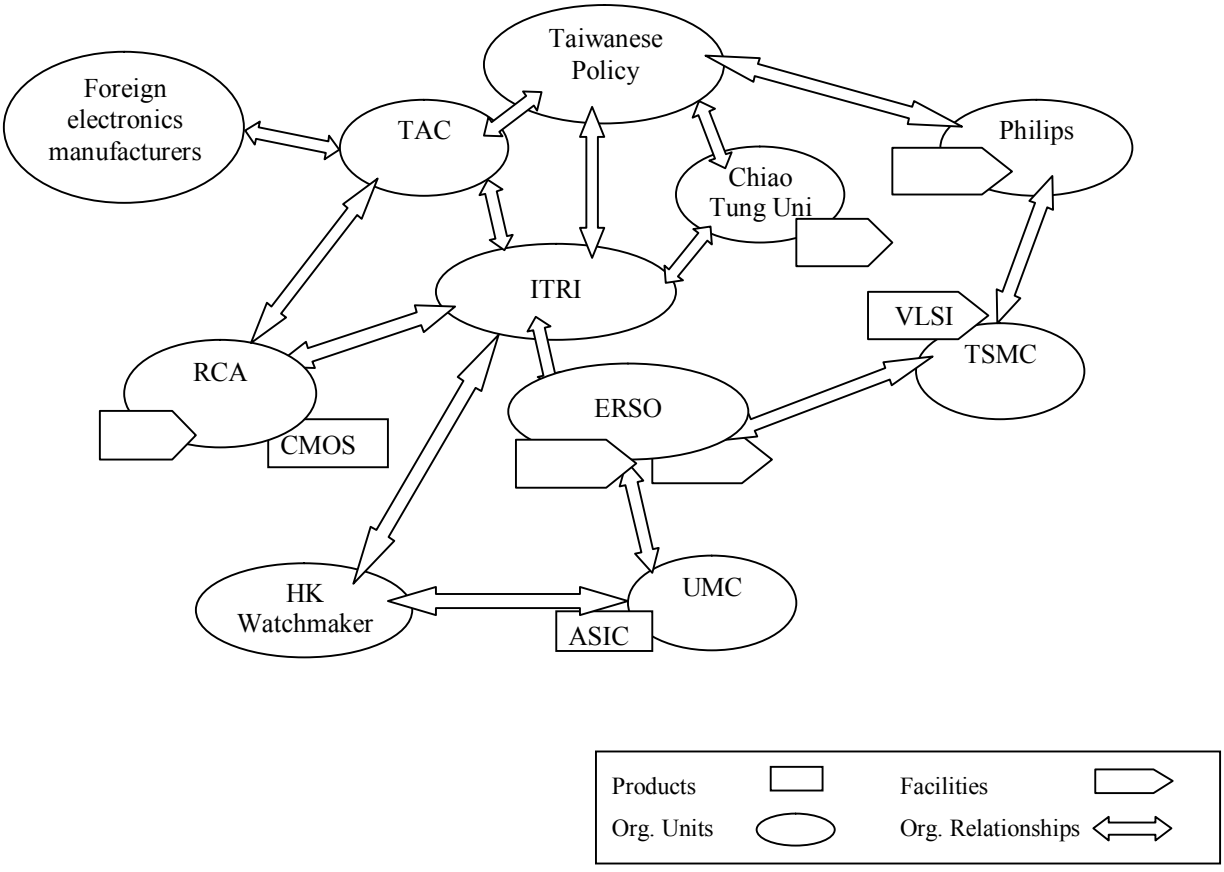
Thus, the "upstream" and "midstream" levels are mostly involved with developing activities, and the "downstream" sector is concentrating on production, but what about the using setting? In Taiwanese policy plans, users, i.e. the customers, are taken for granted and the focus has been targeted towards identifying general user needs and directing development and production of new solutions towards suiting these needs. In other words the users are considered to be passive and not particularly involved in development or production. It is with this view, which neglects an important part of how innovation comes into being and how value is created, that an inherent problem resides. Although the biotechnology sector in Taiwan has grown considerably in the last decade, the commercial outcome has not achieved the results expected by investors and policymakers. A lack of commercial users of what is being developed and produced has clearly amplified the view that biotechnology in Taiwan is a failure. As it has been suggested that the biotechnology is a disappointment or even a failure, due to the lack of commercial use of what is developed and produced, it would be natural to suggest an increased attention be aimed at the using setting, and its interaction with developing and producing settings. An analysis based on quantitative measurements of inputs and outputs does not provide adequate explanations to why the using structure and its interaction with developing and producing structures is weak.

In the next sections we will take an interactive and non-linear view of development, production and use, but let us first conclude this section. As has been shown, the emphasis of contemporary Taiwanese industrial and innovation policy has been: (1) To create innovation and industries here and now; (2) To use novelty as a main source of new economic resources and; (3) To linearly transfer research results from science to industry. These characteristics will be discussed more thoroughly later, but before doing so the empirical material will be viewed from a resource interaction perspective. This will give an empirically-based understanding of how innovations come into being and bring forward a complementary picture to the policy understanding. Furthermore the analysis will look at the indirect effects of certain government measures and which consequently can aid in identifying areas that require more attention from policy.

8.2 Interaction between resources in the semiconductor case

In the analysis of the Taiwanese semiconductor industry, it is the interaction between resources involved in the emergence of the semiconductor industry, in different settings and between them that is of interest. This process will be viewed from three different structures in developing, producing and using settings. Although there have been many interfaces worth studying, only a few with relevance for the scope of this research are discussed. Figure 8.1 below is a network map of some of the key resources in the emergence of the semiconductor industry[101].

Figure 8.1: Network map of key resources involved in the semiconductor case



[101] In Figure 8.1 the interfaces are not mapped out, instead the main interfaces between the resources are discussed in the subsequent text.

The developing setting

Let us first consider the developing setting. In 1973 ITRI was commissioned by the Taiwanese government to develop semiconductor technology and build up an industry. According to many accounts, including the government interpretation, this was also the formal start of the Taiwanese semiconductor industry. In this section what will mainly be considered is the structure of physical and organizational resources around the research institutes that were assigned by the Taiwanese government to handle development of semiconductor technology and some of its interfaces with producing and using settings.

Connection between organizational and physical interfaces: A developing structure emerged in Taiwan with a clear aim of the Taiwanese government to quickly speed up Taiwan's entry into the global semiconductor business. It was done through creating the public research institute ITRI in 1973 and a year later with the establishment of ERSO. The universities were not considered by policy to be an important part, although National Chiao Tung University had already established Taiwan's first semiconductor laboratory in the early 1960s. However universities played a significant role in training and educating the personnel at ITRI. The capabilities and knowledge within ITRI emerged over an extended period of time. An important factor in the establishment of the local developing structure was existing sources of semiconductor knowledge. The empirical material illustrated how much of the knowledge of semiconductors stemmed from Taiwanese professionals working within existing companies and research environments. Through these connections the door was opened to a rather special source of knowledge.

Almost all the experts engaged in the expert committees that the Taiwanese government created, were "overseas", or US-based Chinese and Taiwanese engineers involved in semiconductor development in academia or business. It was these experienced semiconductor experts who helped set up ITRI, and ERSO. Hence, already from the start of attempting to develop a domestic base of semiconductor technology, Taiwanese policymakers and engineers were interacting with individuals working in companies and research units that were world leaders in the field of semiconductors. This created a large number of organizational interfaces not only to other developing structures but also to existing producing and using structures mainly in the US. It was through these interfaces that ITRI was able to get access to technologies (in the beginning a mature one, but later also more advanced ones), and knowledge.

The developing structure was not only built up through the help of experienced people and organizational units outside of ITRI. In addition to the creation of such organizational interfaces there were also important physical interfaces that shaped ITRI and the developing structure to what it is today. One important physical interface was, for example, the mature technology that ITRI licensed from RCA in 1976. Even with a big pot of money from the government, to develop semiconductor technologies and to help start a local industry, the technology was not just going to come from nowhere. ITRI needed technology, to experiment on and learn from. When it became clear that no advanced producer was interested in licensing any cutting edge technology to Taiwan, the only viable solution was to try and license mature and outdated technologies. This was also a more practical solution considering the economic constraints for the project and the lack of semiconductor research and business experience among the personnel at ITRI at the time. Thus RCA's offer to license out an "obsolete" technology served an important purpose, as it educated ITRI and its staff on how to manufacture semiconductors. The fact that it was mature had several advantages. One clear advantage was that it was already thoroughly tested in existing producing and using structures, in other words, the technology already had established user and producer interfaces.

Another aspect of ITRI choosing RCA was the support program which the licensing deal provided. RCA offered a complete production technology, including process design, product specification, testing technology and also training for 37 Taiwanese engineers at RCA in the US for a year. Due to the fact that the technology transfer also entailed extensive personnel training, ITRI had a large number of trained engineers in semiconductor development by the mid 1970s. In addition RCA helped ITRI set up a fully operational production facility for CMOS technologies. Since the technology transfer was accompanied by interaction related to other complementary resources, semiconductor development could progress quite quickly. However, as mentioned earlier, this did not lead to any major achievements commercially. The explicit goal of the developing structure was not primarily to make economic returns on the investments made up to that point, at least not at this stage. The main aim was to learn how to develop and produce semiconductors.

In the following two decades after the birth of ITRI the developing structure became incrementally more advanced. As was demonstrated in chapter 4 both policymakers and the professionals working in the developing structure seemed to be aware that it would take some time to build up knowledge concerning a new field and technology. New production facilities and technologies were developed through the connections made to established producer-user

structures. Production-wise, the technologies developed were, in the mid-1990s, on a par with world standards, in large part due to the producing structure that emerged in Taiwan.

The producing setting

Through the activities undertaken, ITRI and ERSO were gradually able to learn more of development and production of semiconductor technology. For example, ERSO improved the CMOS technology in the production facilities created with the help of RCA. Eventually a part of ERSO's production facility was spun off into a new company, UMC. Later ERSO's VLSI production facility was spun off, laying the foundation to TSMC. Not only were these two spin-off companies the first two Taiwanese producers of semiconductor technologies, but they have also become two of the largest in the world in semiconductor foundry.

Connection between organizational and physical interfaces: There was not much business interaction between the government-created semiconductor producers and established using structures up to the mid-1980s. There were no large advanced customers of the technologies being developed at ITRI. It was not until almost two decades after the creation of ITRI that a larger producer-user network could be distinctively noticed in the economic statistics. However, over these decades an intricate network of interfaces to producer-user settings had emerged. In this period the developing structure had already had extensive interaction with established business structures, which was also inherited by the producing structure, as these were direct off-shoots of the developing structure. What the empirical material indicates is that the organizational interfaces that were created were often not consciously part of an ambition to build up a semiconductor industry. For instance the relationships, developed between foreign electronic companies and the Taiwanese government were built up over decades, starting with the establishment of a foreign-owned electronics industry in Taiwan in the 1960s. The activities to develop semiconductor technology as well as business in the 1970–1980s were thus undertaken in an environment where major global suppliers of semiconductors were already active in the Taiwanese economy, as producers of electronic appliances. As relationships between Taiwanese companies, policymakers and the foreign companies were established, there was continuity in their interaction. However, it was after many years of infrastructure build-up and commitment from the Taiwanese government that

some of the foreign companies present in Taiwan eventually became to some extent interested in the Taiwanese semiconductor industry.

Until the 1980s the capabilities and technologies of the producing structure had already been built up through a large number of resource combinations with existing developing and producer-user structures. As mentioned, the mature CMOS technology from RCA was an advantage for the establishment of a producing structure. Even though the technology that was further developed by ITRI was trailing far behind leading standards in terms of technological sophistication, it had its advantages. From a developing perspective the "lack of novelty" could be regarded as something negative. This characteristic of the technology, however, made it possible for ITRI to connect directly to both existing producing and using structures. For example, since the technology was considered obsolete, RCA was willing to help ITRI set up a production facility without fearing competition. The production facility that was established was fully functional and ready for the development and production of CMOS semiconductors within a year after the signing of the contract with RCA.

One of the most highlighted events in the creation of technological interfaces occurred with the formation of TSMC. The company was created through spinning off a VLSI production facility at ITRI, but advanced semiconductor technologies and production methods were also given and licensed over to TSMC by Philips. This resource combination brought forward a new production process, semiconductor foundry, which in retrospect turned out to become a money-earning business model for both TSMC and UMC. The development also brought advanced production technology to related interfaces. For example, ITRI was able to upgrade its capabilities, facilities and technological levels. Furthermore a large number of suppliers and sub-suppliers to the producing structure were able to benefit from this development.

The products and known applications of the CMOS technology made it easy to identify existing users. Shortly after ITRI had developed its own CMOS technologies, the research institute had also found a customer, a watchmaker. When UMC was spun off from ITRI it inherited both a production facility and its first customer. Thus the first Taiwanese semiconductor company became a producer of reliable but non-advanced semiconductors, catering mainly for small South-east Asian electronic companies. This changed, however, when Philips became interested in a joint venture with ITRI. The creation of TSMC had a profound effect on the Taiwanese semiconductor industry, and also the global semiconductor business. The birth of the semiconductor foundry and Taiwan's flagship company TSMC was the result of the interaction between ITRI, Philips and the Taiwanese government. These

organizational units had at the time goals which were commensurable. The Taiwanese government wanted to create an industry and ITRI had reached a stage where it could spin-off a part of its facilities. For Philips there were clear business opportunities to outsource its production. Philips transferred technology, know-how, a cross-licensing portfolio, as well as legitimacy to the new start-up (each resource being instrumental to the development of the TSMC). More important was the fact that TSMC had one of the largest electronics companies in the world as its customer from the start. This allowed TSMC to upgrade its manufacturing technology and skills in a short amount of time. Becoming a supplier to a large and advanced user not only proved beneficial in upgrading the technology of TSMC but it also drew the attention of other large electronics companies such as Intel and Texas Instruments to mention a few that later also became customers of TSMC.

The using setting

Let us now continue with a closer look at the using setting and more specifically at some of the established companies and resource structures associated with the users. How does the emergence and development of the Taiwanese semiconductor industry appear from this perspective?

Connection between organizational and physical interfaces: The connections of the Taiwanese industry with a using structure can be traced back to the multinational electronics companies that had already established business activities in Taiwan in the 1960s. When ITRI was created and later became a hub for development activities it already had connections to existing producer-user settings. However, as was mentioned in chapter 4, Taiwanese policymakers did not believe that the foreign electronics companies played an important role in the emergence of the semiconductor industry at that time. It was their belief that the business units of the foreign companies contributed to Taiwan's economic growth but little to high value-added industrial development. It was not until the mid-1980s that they were considered to have an important role by the Taiwanese government. As the empirical case shows, however, it is difficult to separate and neglect the role the foreign companies played before the Taiwanese industry started to grow rapidly in the late 1980s. Although the presence of the foreign companies in Taiwan in the 1960s had no immediate impact on the development of advanced semiconductor technology in Taiwan, it served as an important

platform whereby important relationships and commitments came to be established. By the time the Taiwanese government decided to promote semiconductors and ITRI was created, foreign electronics companies had been present in Taiwan for over a decade contributing to educating the Taiwanese workforce. Several new electronics suppliers were indirectly created through Taiwanese workers starting their own businesses. Furthermore, established Taiwanese companies also received a share of technologies and business as they were seen as important business partners to the foreign companies.

A major reason why the advanced semiconductor companies were not customers of Taiwanese semiconductor products is quite simple. For a long time the Taiwanese companies did not offer any complementary resources which they sought, there was simply no fit. Most of these advanced companies were fully vertically integrated concerning design and production and had no interest in what was being developed at ITRI. The only part of the production which was outsourced was the testing which did not require any advanced capabilities. Thus in the beginning ITRI's technologies catered to a largely "low-tech" segment of the user market. ITRI and later UMC was thus not regarded as a threat by the top semiconductor manufacturers, neither did they produce anything of economic value for them. It would have been unlikely for the foreign companies to have gone to Taiwan to start setting up advanced R&D laboratories prior to having benefits in terms of added value to their investments. For example, UMC, the first Taiwanese producer of semiconductor technology, was not backed up by any established business users, there was simply no interest from the advanced foreign companies. Taiwan and UMC had little to offer these companies in terms of technology or business even up to the 1980s. TSMC, on the other hand, received support from an advanced user, Philips, which was offered as an opportunity to create an external supplier.

On another note, about two decades after ITRI started to engage in the CMOS technology it had emerged to become a dominant standard in integrated circuits. From a using perspective the features (for example, low power consumption) were much more important than novelty and untried solutions. The CMOS technology later became a niche product which ITRI's spin-off UMC was one of the few manufacturers to supply. Of course this could not have been known by Taiwanese policymakers at the time of the technology transfer. However, an important aspect to point out is that it was enabled due to the fact that it could increase the value of the users' existing resource structures, and thus providing opportunities for Taiwanese companies as suppliers of semiconductors.

As discussed above, the advanced end of the user spectrum, i.e., the established global semiconductor companies were not interested in another company that could develop advanced technologies. Instead the solution that was created, and which provided a complementary resource base to these advanced users' existing resource structures, was a Taiwanese company, TSMC, which supplied advanced semiconductors based on users' specifications. This business was not a result of ITRI creating a high-tech production plant and then finding customers. The demand was created through interaction between the developer and an established business structure. For example, the business relationship between TSMC and Philips was based on a long history. Philips was a pioneer, the company had already been in Taiwan since 1961 and over the years the commitment also came to grow stronger. When the Taiwanese government searched for a partner to form TSMC, Philips was a potential candidate. Other companies that were approached were Intel and Texas Instruments, all advanced semiconductor companies. However, in the end, Philips turned out to be the only serious candidate, not only because it had the resources but equally important was its long-term dedication to Taiwan. It must be taken into consideration that TSMC was an unproven business idea. The burden of proof was on ITRI. Texas Instruments and Intel were just not convinced of TSMC's potential. However, for Philips the incentive to invest was to increase the value of its already made investments. The company also wanted a supplier for a set of VLSI technologies, the leading standards at the time. The idea was something which quickly became embedded into the existing structure of related producer-user interfaces. Later on TSMC also became a major supplier to other semiconductor companies such as Intel and Texas instruments among others.

Comments

What the semiconductor story has shown is how structures related to use, production and development often exist simultaneously. In this specific case, development happened in close relation to already existing using and producing structures. The close relations of the various settings functioned as a catalyst for the emergence of a semiconductor industry in Taiwan. However, the development of the semiconductor industry was not an overnight success, the semiconductor industry did not just surface in a semiconductor virgin land. The picture that the analysis gives shows how the development, production and use of semiconductors came about through interaction between both established and new resources over several decades.

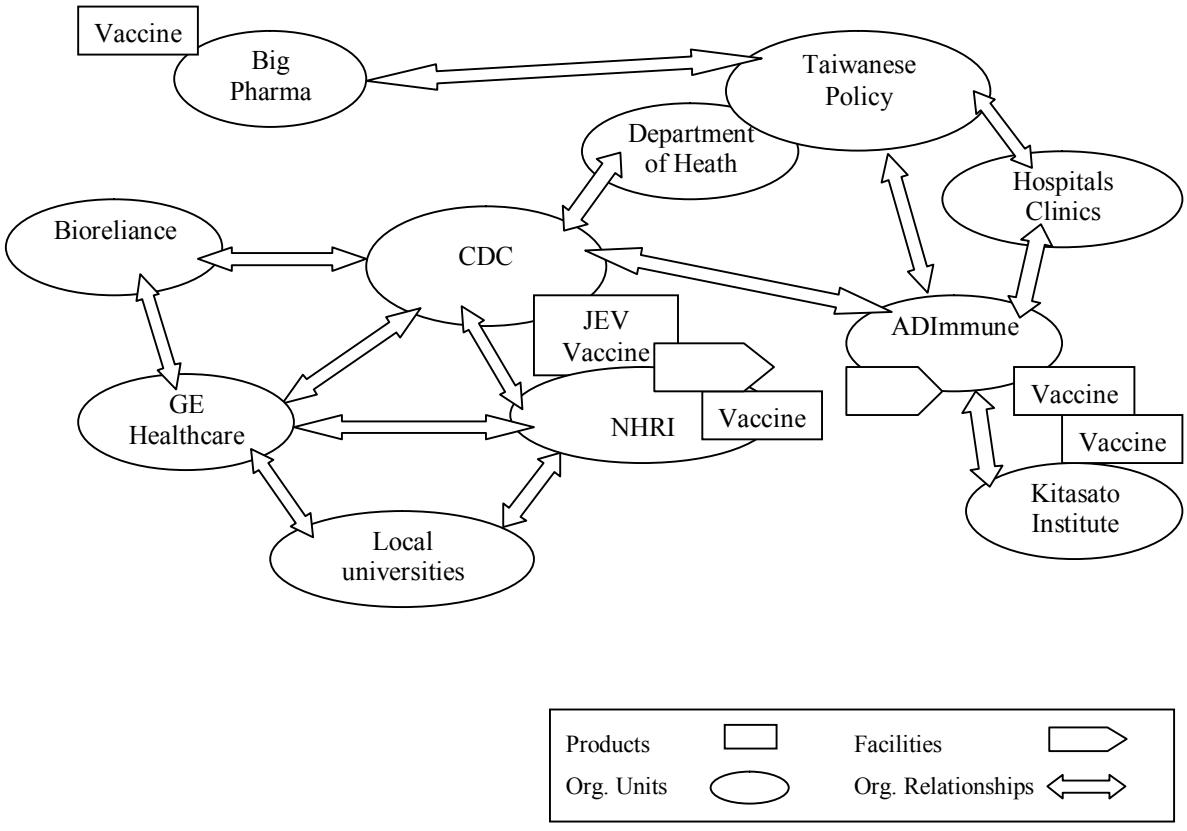
For example, the foreign electronic companies that had established their presence in Taiwan in the 1960s were important to the Taiwanese semiconductor industry's development. Although the foreign companies were not active, in the 1970s when ITRI started its mission by directly supporting the Taiwanese industry with knowledge, technology and funding, specific interfaces can be traced to these actors and their early activities. The relationships which were established between Taiwanese and foreign companies provided knowledge to Taiwanese employees, gave rise to new companies, and set the foundation for the electronics industry (which later became a source of users of Taiwanese semiconductors). Thus the foreign companies had an important role in establishing developing and producing structures.

Another important of aspect of connecting to already existing structures was when ITRI choose to license a mature technology. Although the technology lacked novelty, which was considered as a weakness by the using setting, it became an advantage for a nascent industry as it allowed the main developer, ITRI, to work on solutions suitable for both production and use. Thus Taiwan's development in semiconductors was possible in the beginning because it relied on the established structure of an already tested technology. Consequently an important reflection is that it was not only the new institutions that policymakers created that had an imprint on the development. More important was the ability to take advantage of the already embedded resources, including sources of technologies, production plants built in different moments and even international customers located in Taiwan with consumer electronics assembly plants such as Philips. Overall, the semiconductor case shows how development was achieved by relying on the existing network of resources, both locally and internationally; within and beyond organizational borders.

8.3 Interaction between resources in the Japanese encephalitis vaccine case

The analysis will now move on to biotechnology, which is illustrated through the analysis of two different biotechnology projects, one related to the Japanese encephalitis vaccine and the other related to liposome-based drugs. What will be analyzed in this section is the development, production and use of a vaccine for Japanese encephalitis. As was demonstrated in the empirical material, the vaccine project has been strongly guided by government units. Naturally the resources involved have a strong connection to Taiwanese policy. In Figure 8.2 below some of the key resources involved in the Japanese encephalitis vaccine case are illustrated.

Figure 8.2: Network map of key resources involved in the vaccine case



The developing setting

The developing setting in the vaccine case is directly or indirectly related to Taiwanese policy which to a large extent has influenced what actors and resources are included in the development. This section will be concerned with the resource structure surrounding the main developer of the Japanese encephalitis vaccine, CDC, and some of the interfaces with producing and using structures. Below we will take a closer look at some of the resources involved in the development of the vaccine.

Connection between organizational and physical interfaces: It was with the ambition of building up a national vaccine capacity and industry that the development of a Japanese encephalitis vaccine was commissioned by the Taiwanese government in 1997. The development direction of the vaccine was from the start characterized by a top-down management by the government with clear specifications of time schedules and which actors to involve. The main developer became a newly-created vaccine center at the CDC. With the support of the government and other research institutes, a vaccine was to be developed within a few years. Although none of the organizational units were experienced in vaccine development and commercialization, the Taiwanese government had already planned out the major details of development, production and use of the vaccine, with the specifics of the clinical features left to the developing unit's own discretion to decide.

In large part, the policy-created network of organizational resources was centered around the CDC. New local actors were given incentives to work with the vaccine center in developing a vaccine, such as universities, local companies and other research institutes. The research group at the vaccine center developing the vaccine had however few connections to existing vaccine developing structures. With this organizational configuration the development, production and use of the Japanese encephalitis vaccine had been planned out by the Taiwanese government. The proposed plan was nevertheless delayed. On the executive level the development was not that straightforward as it was not just to develop and produce something which already had a customer. The actors lacked knowledge and experience in vaccine development. For example, the collaboration between ADImmune and CDC showed how the inexperience and different goals of two different organizations severely delayed the development of the vaccine. Without any established connections to existing producing structures, there were many things that needed to be learned from the beginning.

The Japanese encephalitis project was not based on any new cutting edge technology or production method. Instead the development was done using an old method which had already been in use for several decades. Even so the project group had difficulties with developing the vaccine. A large reason was the lack of experience in vaccine R&D. The vaccine center at the CDC did initially not have experienced personnel, nor were the facilities at the time approved for any larger vaccine production. The laboratory and facilities at the vaccine center was nonetheless equipped enough to conduct pre-clinical testing. In parallel the government was infusing money into other research institutes to build up laboratories and production facilities for vaccine development. For example, with the Japanese encephalitis vaccine experience partially in mind, the facilities at NHRI were being built up under the auspices of the government. Experienced personnel were hired and more efforts were taken to comply with the high regulatory standards for vaccine development and production. Over a decade after the start of the Japanese encephalitis vaccine project, an improved infrastructure of research facilities, advanced laboratories and experienced personnel had started to emerge, although the handful of vaccines, including the Japanese encephalitis vaccine, now being developed was at this stage still in their nascent stages.

As discussed there were few interfaces between the vaccine center and other existing vaccine developing and producing structures. Due to these circumstances the vaccine center was initially left to its own ingenuity when trying to develop a vaccine. However, an important source of knowledge came from an established business relationship. GE Healthcare, a supplier of biotechnology equipment to the CDC, came to have an important role in the development activities. The government had not paid much attention to this possible source of knowledge and GE Healthcare was not officially a part of the development network of the vaccine. Nevertheless the business contact between CDC and GE Healthcare did benefit the vaccine development. GE Healthcare aided the researchers at the CDC in understanding more of the development and production of biologics, and the regulatory procedures that needed to be followed. GE Healthcare also helped the CDC with finding Bioreliance, the Scottish contract research organization which later performed the bio-safety testing of the vaccine. Thus GE Healthcare was not only a supplier of hardware and material, but was also a knowledge provider and helped create organizational interfaces with existing business structures. GE Healthcare was furthermore a supplier to the NHRI, and assisted in setting up the production facilities there.

The producing setting

The producing structure surrounding the Japanese encephalitis vaccine has been largely funded by the Taiwanese government. There were no facilities for large-scale production of vaccines in Taiwan when the Taiwanese government started to promote local development. Thus the government gave the NHRI the directive to establish production facilities at the beginning of the new millennium. The producing capabilities were to be built up within research institutes so a larger scale of collaboration would be made possible with both upstream and downstream units.

Connection between organizational and physical interfaces: As part of its larger ambition for vaccine production, the Taiwanese government had decided that the NHRI was to become the hub for vaccine development as well as an integral part of the production of vaccines. On a planning level, what were to be connected were both local and foreign research units for the production of vaccines. What could be distinguished in the activated structure of this objective was foremost the joining of the vaccine center at the CDC with the NHRI. Additionally research universities were given incentives to collaborate in educational and research purposes. These activities would of course not yield any short-term benefits in vaccine development and commercialization.

The creation of interfaces with existing business structures was however complicated. As illustrated in the empirical material attempts by the Taiwanese government to attract multinational vaccine manufacturers were going slowly, and the initiative to include local producers was not in line with expectations. For instance, the attempt to transfer the Japanese encephalitis vaccine to ADImmune had not resulted in any advancement of the vaccine and the CDC had to take it back after a few years of inactivity. One problem with the artificial interface between CDC and ADImmune was that the knowledge on how to develop or produce the vaccine was not increased. CDC was supposed to offer support but none of the organizations really had any experience in developing and producing vaccines. The government's attempt to speed up development by handing over the vaccine to ADImmune was thus already from the start a risky project. Even if personnel would have moved from one organization to the other this would not have created a significant knowledge increase for any part. Moreover the goals of the involved actors were very different. What the government and the CDC wanted was a vaccine that was economical and easy to develop and produce. ADImmune, however, stressed other aims which included the creation of novel vaccines.

From the above discussion it can be understood that the organizational interfaces in the producing setting, created over a decade, were superficial. The main interfaces of the producing structure were with local developing structures such as universities and research institutes. These were largely inexperienced in vaccine development and production. A proposed solution to the problem of a weak producing structure was to invite global pharmaceutical companies to set up research and production operations in Taiwan. These organizational units did however not have any major incentives to relocate to Taiwan. Hence there were relatively few relationships to established producing and using structures, and the actors had goals which were very different.

The observation that the producing structure lacked deeper interaction with other settings is not very remarkable. One reason is that establishing a production facility for biologics is a complex and expensive task which requires time. Machines and systems need to comply with regulatory standards. The requirements for certification are extremely rigorous considering that it is vaccines that are dealt with. Even if the Japanese encephalitis vaccine had been finished quickly, the CDC would not have had access to a production facility which was certified to produce vaccines. Furthermore to set up facilities and to start producing vaccines required the assistance of knowledgeable people. The government did later engage expert committees composed of overseas professionals and experts in the development of vaccines. With this support, a few years after the initial development of the first local vaccine candidates, the production facility at NHRI was on its way to be set up and to meet the terms of the required standards. However, this experience concerning the amount of money, knowledge and time needed to have a functioning production facility also demonstrates the steep uphill-struggle to establish local companies, either through engaging already existing companies or creating spin-offs. As opposed to developers, the producers have large overheads and fixed costs from investments to recover, implying a need for customers. Since interfaces to any established business structures and large customers were few, encouraging a local industry to participate was not going to happen just through some government incentives, especially without any vaccines.

In the organizational interfaces which the government was trying to create there were definitely benefits for the actors involved. For example, by being recognized by the government as a leading producer of vaccines in Taiwan, ADImmune became eligible for extensive support. Little did it matter that ADImmune was actually more interested in developing its own line of Japanese encephalitis vaccines rather than investing resources in developing CDC's vaccine, for which the government support was intended. The Taiwanese

government and ADImmune obviously had different goals and intentions with the vaccine. This was clear as ADImmune had only paid 1 NTD for the license and the company did not seem to see any economic value in the vaccine candidate. If a technology acquisition had a real value for the company it would have been reasonable to assume that a higher licensing fee would have been paid. Instead a large project grant was given and it was partly used by ADImmune to set up research facilities and also to acquire more advanced development methods. Apart from the monetary support it is important to recognize that the transfer did not bring any increased research capabilities or knowledge, what we had were primarily two inexperienced units engaged in the transfer. As no complementary resources were really combined, the project was risky from the start. This example is indeed evidence for the importance of connecting to established knowledge sources and also users.

The using setting

We will now take a closer look at the vaccine project from the perspective of the using setting. What was to be developed and produced already had an intended user, the Taiwanese government. Since the funding of the vaccine came solely from the government this also meant that the government could exercise a large control over the development in terms of what actors to include and what resources to utilize.

Connection between organizational and physical interfaces: As the empirical material has shown, the Taiwanese government commissioned the Japanese encephalitis vaccine and funded the development and large parts of the production. Since the funding of the vaccine came from the government, it meant that Taiwanese policy could influence the vaccine development and production in terms of what resources to be utilized, such as different domestic research institutes and private manufacturers et cetera. For the use of the vaccine there was already a using structure, consisting of a government-directed healthcare network in place. What the Taiwanese government wanted was mainly a functional vaccine and the possibility to somewhat control its supply. The distribution to hospitals and clinics would be done through the government healthcare network. Within the realm of the government's aims was also to try to establish a domestic vaccine industry (including research as well as production). To reach these goals the Taiwanese government was very active in trying to connect different local companies and set up an infrastructure.

The physical resources related to the using structure were largely interfaced with government units, for instance, the research and production facilities at the research institutes which have been funded by the government. When the government decided to initiate the domestic development of vaccines, the foremost reason was to secure a domestic supply of vaccines against diseases with a high incidence among the Taiwanese population. What was wanted in the case of Japanese encephalitis was a cheap and functional vaccine to administer through the national vaccine program. Thus the Japanese encephalitis vaccine has been embedded in a local physical structure created by the Taiwanese government. The efforts have not created any physical interfaces to existing using structures outside of Taiwan, however. The attempts to create interfaces to global vaccine manufacturers and their physical structures have hitherto not succeeded. The main reason has been discrepancies in goals and the lack of fit between existing resources.

Despite being the main architect of the development network, the policy units did not have much influence on the clinical features of the Japanese encephalitis vaccine. The overview the government had was on a superficial level and the development directions were also given accordingly. The decisions made were highly political, for instance producers and collaboration partners in the policy-created network mainly needed to be Taiwanese, especially on the production side. The policies made were quite volatile, however, with drastic changes in directions and goals. The senior management of research organizations was put in office through decisions made by government. Also the amount of funding readily available for research and industrial development was stable, but was allocated inconsistently depending on political situation. Such a short-term, goal-oriented decision-making environment would indeed conflict with the long-term goals of developers as well as established producer-user structures.

Comments

This case is a clear example of how Taiwanese policy has tried to steer both scientific and commercial activities. The ambitions to create a local vaccine industry all the way from research to use have been accompanied by high expectations, however the results have been disappointing to Taiwanese policy. After more than a decade of trying to develop a Japanese encephalitis vaccine with a standard method, the vaccine is far from being finished. The project has systematically lagged behind government planning and been considered a

disappointment by the actors involved. The example of the Japanese encephalitis vaccine is an interesting example of the complexities involved in trying to create development, production and use of new resources. Although a well-known method of developing a vaccine was used, after a decade it had still not been developed. One main reason for this was that the developing structure consisted mainly of inexperienced developing units. There was also no intermediary structure, even if a vaccine would have been developed there was no producing structure. Although production facilities were being built up, having them certified and approved is a process which takes time. Furthermore several conflicts arising from interaction with producing and using structures led to incongruent goals. Largely due to these factors, the vaccine is still at a nascent stage after over a decade.

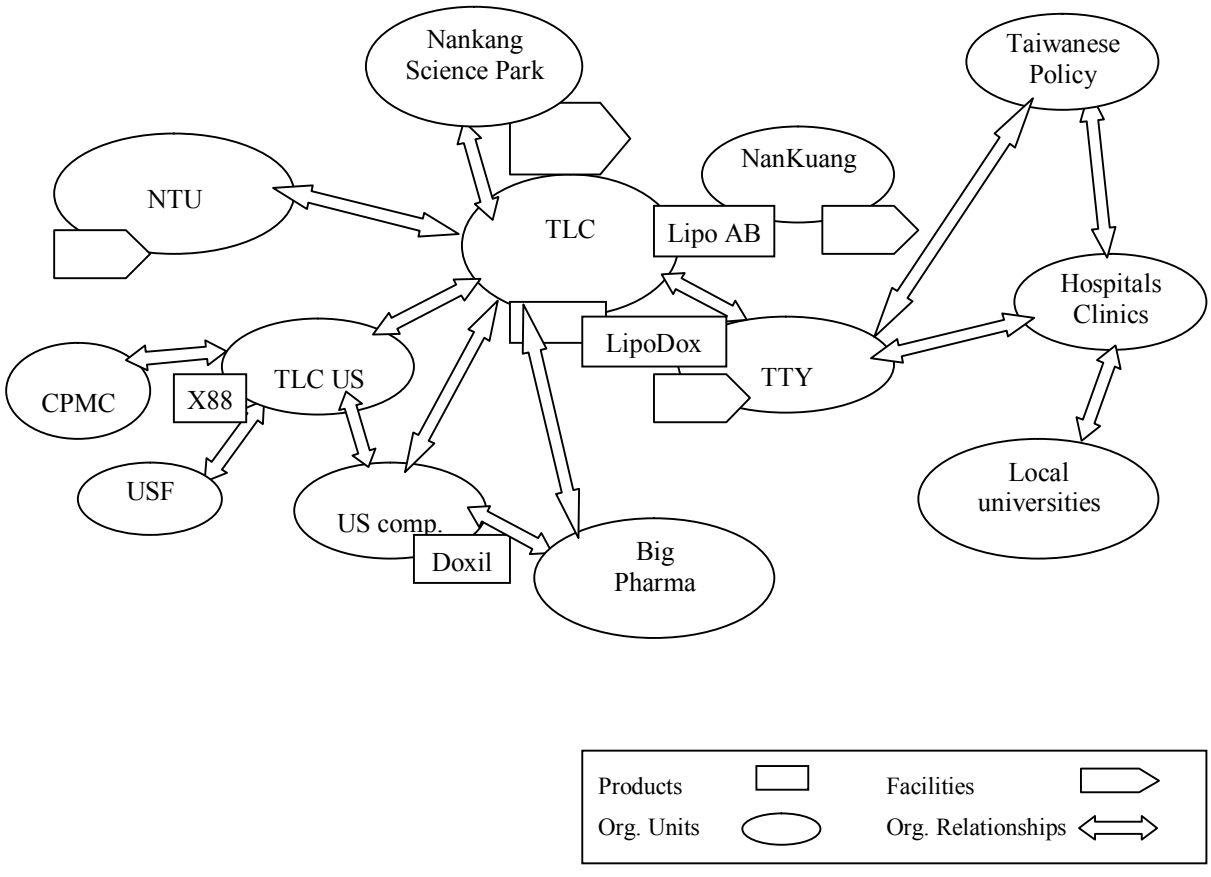
The policy measures have over time created a physical infrastructure and direct interfaces between a number of physical and organizational resources, but, as the case has shown, being able to create interfaces does not necessary equate deep interaction. Whilst the government could influence certain directions, it could not control how the actors interacted or how resources were used. Another important observation from the analysis is how all the actors involved had their own agenda. Sometimes there was congruence of goals, other times goals conflicted. For example, in retrospect it is obvious that the decision to transfer the vaccine over to ADImmune seems quite hasty and uninformed. This shows clearly how difficult it is to plan and coordinate a development process. The analysis underlines the importance of established interconnections between physical and organizational resources to which new solutions can be related. Of course such endeavours require time, a very important aspect in development, production and use. However, patience was what policymakers did not seem to have. As demonstrated, the ideas of policymakers kept on changing faster than the activated structure allowed.

Should this government attempt at building an industry and creating vaccines be considered a failure? It has been a learning process, more knowledge has been achieved through trial and error, and also through hiring more experienced people. An infrastructure is slowly being built up, where the activated resource structure is consistent with developing vaccines.

8.4 Interaction between resources in the liposome case

Chapter 7 portrays a complex network of various actors and resources involved in developing, producing and using liposome drugs in Taiwan. The combination of various resources such as technologies, products and business relationships with scientific partners, customers and technology partners/distributors have stretched over geographical borders and several decades. In comparison with the Japanese encephalitis vaccine project, the liposome project has not been directed by Taiwanese government policy. Figure 8.3 shows some of the key resources in this case.

Figure 8.3: Network map of key resources in the liposome case



The developing setting

The picture of the development of liposome-based drugs portrays a process which has extended over several decades and spatial borders. As discussed above, the discovery of liposomes was made in the 1960s and early on the potential of applying it to drug development was identified. However, liposomes were difficult to apply to drug-synthesization and it was not until the 1990s that the first commercial applications were available on the market.

Connection between physical and organizational interfaces: From the beginning it was academic units which drove the development and increased understanding of liposomes. Later on, when commercial applications were developed, the involvement of research-intensive organizations was still very significant. In Taiwan the development of liposome drugs was initially made by a research group at a university. It was already a part of a strong research network built up over two decades and had extensive relationships to existing developing structures and producing structures in the US. For instance, many of the individuals had been educated in the US and involved in a setting where liposomes were being developed and commercialized. The relationships which the Taiwanese research group had to both research units and organizations that had commercialized liposome drugs was indeed an important factor when engaging in scientific and business activities in Taiwan. For example, these resource ties meant that the main Taiwanese developing unit had practical experience and access to past clinical development protocols et cetera. Hence the knowledge of liposome technology was already acquired long before the development of the first liposome-based drugs in Taiwan.

When liposome technology was introduced in a Taiwanese context in 1997, it was in an academic setting. The intentions were to create a research group and publish academic papers. For this aim, the research activities were undertaken at a university. Later on when the research group at the university decided to set up its own company, TLC, the activities were still performed in the university laboratory. There was no need at this stage for any special research or large-scale production equipment, in addition to what could be found in the laboratory. The research group was able to go from academic research to drug development so quickly due to its experience and connections to existing developing and producing structures. The university laboratory, sufficient for academic activities and pre-clinical testing, was not

enough for larger-scale production or more advanced testing. This was partly solved by drawing on research connections in more advanced laboratories in the US.

From the beginning, Taiwanese liposome drugs were developed in an extended development network with connections to existing resource structures abroad. The knowledge of development, which TLC had, was acquired from advanced developers and producers mainly in the US. Locally, resources were initially sparsely used and there were no deeper collaborations with domestic universities or research institutes. The interaction with government sources was at first mostly indirect as Taiwanese policymakers did not want to support TLC's development projects. When the government denied funding for TLC, it was on the grounds that the drug candidate was not novel enough. Government officials made the assessment that the combination of a new liposome formulation and generic drugs had little commercial potential and uniqueness. The financial constraints and lack of government support meant that the developing structure had to find alternative ways of support. In retrospect some of these choices also turned out to be beneficial for the development. For instance, the choice to turn to established local producers of generic drugs.

The producing setting

As illustrated in the empirical material, the development of liposome drugs took a relatively short time (e.g. LipoDox took four years from the initial testing to the drug being available on the Taiwanese market), largely because of the experience of the developing unit and its connection to existing developing structures. However, a problem was encountered when LipoDox was entering clinical trials. The larger-scale production of the active ingredients of the drug required a more advanced production structure which could also perform clinical trials. This issue was resolved by connecting to existing local producing structures.

Connection between physical and organizational interfaces: The development of liposome drugs in Taiwan was embedded in a larger global network of actors, of which some had already commercialized liposome drugs. The interaction and relationships to various leading research units and companies in the US had been active for over two decades and made it possible for the main developer in Taiwan, TLC, to keep up to date with what was happening in the field. Later TLC also set up a subsidiary in the US, in order to be closer to established developing settings and be able to attract top level researchers in the US. For production and

clinical trials of liposome drugs in Taiwan, local resources would however have to be engaged to a larger extent. Instead of undertaking production alone, TLC entered partnerships with local pharmaceutical companies. Many of these were already well established in Taiwan, having knowledge of clinical trials processes, connections to hospitals (with large patient pools) and existing production facilities. Thus they had the complementary resources necessary for taking the drug candidates a step closer to Taiwanese users. However, finding suitable producers would also have to entail developers and producers having commensurate goals, i.e., bringing value to both sides of the transaction. The pharmaceutical producers in Taiwan were mainly involved with generic products and were not very competitive outside of Taiwan. As a consequence many larger companies were actively seeking out new opportunities in the midst of the government promotion of biotechnology, especially to find research-intensive development projects. Traditionally these producers had not had widespread relationships to developing units.

The reason for establishing relationships between developing and producing structures was very much contingent on the access to complementary resources. The reasons behind these combinations were the business opportunities that were foreseeable in a relatively short time-horizon. For example, the development of liposome drugs was initially conducted in a university laboratory. When scale-up production was needed, the facilities were no longer able produce the quantities of the active ingredients necessary. The university was not going to upgrade its laboratory for one research group's business endeavours, nor had TLC the financial means to set up its own production facility. An option for production was to turn to a research institute which would have the production capability. The interaction with research institutes was however sparse. Earlier, TLC had contracted DCB to undertake some clinical trials experiments. But apart from for this collaboration there had not been any other R&D cooperation between research institutes and TLC.

Instead the liposome drugs were licensed to and integrated with the pipelines of local pharmaceutical companies, TTY Biopharm and NanKuang Pharmaceuticals. For TTY, LipoDox became a way to strengthen the company's product pipeline. TTY had facilities that could produce the active ingredients of the drugs as well as the liposome formulations. Although LipoDox was not considered a novel drug, it was ready for clinical trials and fitted into the producer's business plans to develop or acquire new cancer drugs, to introduce on the market. NanKuang Pharmaceuticals, which was later involved with the production of the second liposome-based drug was in a similar situation as TTY and wanted to expand its product pipeline. The pharmaceutical companies were providing complementary resources

which the developing setting did not have, for instance, the sales network, clinical trials experience and so on. Later these pharmaceutical companies also came to become more involved as the major financial sponsors of further developing activities.

The limited budgets of the actors in the developing setting resulted in quite practical ways of combining resources. Much of the development was initially based on already existing solutions, protocols, drugs and structures, which also made it easier to fit into existing structures. Although the government had rejected TLC's business proposal, government support was available in other forms. For example, after the development of the first drug, TLC was able to move into a government-sponsored incubation center. The idea of the incubation center was to support start-up companies with issues of technical, regulatory and commercial character. For TLC it offered cheap office and laboratory space, where more advanced drug development could be conducted. For the larger local pharmaceutical companies, government support was easier to come by. Although TTY was involved with generic drugs it was successful in attaining government funding to undertake research-intensive activities.

The using setting

While developing activities were mainly conducted at TLC and at research units in the US, production was done with the assistance of local pharmaceutical companies. In the previous section the producing structure, mainly involving two local pharmaceutical companies, was discussed. In this section we will look more closely at the using structure and the important role it plays in the development and production of drugs.

Connection between physical and organizational interfaces: The organizational units which make up the using structure are different hospitals, a larger distribution system of pharmacies and doctors et cetera. A majority of these are not connected to each other, however, as a collective they are heavily influenced by the Taiwanese context. For instance, the way drugs are purchased and demanded is to a large extent governed by the Taiwanese health insurance scheme. Relationships between pharmaceutical companies, hospitals and doctors are also major influences on how demand is created. The often well established relationships between customers and producers, such as the local pharmaceutical companies, mean that new products, especially those developed outside the established business

structures, are at a disadvantage in finding use. Hence having created connections early to an established producing structure, the new liposome drugs were also able to gain access to a using base. As hospitals and producers were already involved in earlier stages of the development, such as the clinical trials, this influenced the features of the liposome drugs.

The investments in the physical infrastructure among users are not aimed towards production of drugs. If we look at what liposome drugs are mainly used for, which is to treat cancer, it is often the case that users such as hospitals have a great variety of other treatments. A large part of the physical investments made in the treatment of cancer are related to a combination of therapies, for example, other pharmaceutical drugs, radiation therapy and so forth. In this respect it is important for the new product to fit with a larger treatment portfolio of the users, including machines and other products. Although liposome drugs are not directly interfaced with the machines used for radiation therapy, they co-influence each other through the different ways they are used. Even if drugs with superior clinical efficacy are developed, they do not make the other treatments redundant but are rather complementary treatments. Hence, how well new liposome drugs fit into a wide range of other products and treatments is an issue which the users take into consideration as the general concern of the using structure is to increase the value of its existing investments. The features of the new products or solutions are consequently dependent on what the using structure expects of it.

The stability of the using structure in the liposome case provides an example of what happens when something new encounters established structures. In this specific case it has created impediments for novelty. As discussed in chapter 7, how new liposome drugs are developed in Taiwan is to large degree dependent on the using structure and the system in place. Currently the system promotes the development and production of generic drugs, that are often less efficient than novel drugs as they generally have lower efficacy and more side-effects. The Taiwanese using structure and health insurance system has thus created a number of obstacles for the development and production of novel drugs. What has been institutionalized is a system where government regulations and existing investments such as relationships, other drugs and machines, dictate what drugs are valuable. In this respect the existing using structure actually impedes the very efforts which government policy puts into establishing novel drug R&D in Taiwan.

Comments

The example of the development, production and use of liposome-based drugs shows how resources have been combined over an extended period of time and underlines the value of building on existing resource structures. Liposomes were originally not a field which the Taiwanese government believed had a business potential, largely because the products that were to be developed were not considered novel enough. The first liposome-based product was based on an already existing drug and the government did not want to help fund the project. However incidentally, when TLC borrowed university laboratories, the company was indirectly using public research funding. What is illustrated is that, although the role of the government has not been direct, government policy has had indirect effects on the development.

Even if there are more academic research-related resources involved in the liposome case than in the other two cases, many resource interfaces had already been established between developers and existing producer-user structures, and the original scientific discovery had undergone several transformations. Research on liposomes had been conducted for three decades before TLC was even established. After over a decade of business activities and four decades of scientific activity, the making of novel drugs based on liposome technology has only just begun. This point is relevant to stress, in order to avoid a misunderstanding that the Taiwanese liposome project was an example of advanced science being swiftly commercialized.

The fact that the drug was not based on cutting-edge science newly developed at a university contributed to the first liposome drug, Lipo-Dox, being developed and produced in a fairly short time. By using a tested technology and existing clinical protocols, Lipo-Dox was developed and launched on the market within five years. Through building on existing resources, drugs with increasing sophistication have been developed thereafter. However, the novel features of these drugs were not created out of nowhere. The novelty of the later drug candidates were based on a liposome technology which was already available in the 1980s (and with roots from the 1960s), which were combined with chemical compounds developed in another research setting. This time aspect is essential to consider, the founder of TLC had been involved in liposome-related research since the 1970s and development of liposome products from the 1980s. Already from the beginning, the development of liposome-based

drugs in Taiwan was done by people with knowledge of R&D, regulatory issues and commercialization.

The development of novel drugs is very much an interactive process which is dependent not only on the new solution per se, how it is developed, but also on the interaction it has with producing and using structures. For TLC the novelty came in the form of combining several "old" resources in a new context. Although novel drugs can be developed with the current technology platforms, another crucial aspect has been the using structure including the restriction and regulations set by the *Bureau of Pharmaceutical Affairs* (which approves drugs in Taiwan) and the *National health insurance scheme*. Hence, as was discussed in chapter 7, the Taiwanese regulatory environment is not fully capable of approving novel drugs and promotes the use of generic drugs. Moreover, the using structure has large existing investments and strong economic reasons to use generic drugs. Even if a novel drug was developed in Taiwan, it would be difficult to get it approved as a novel drug and find a widespread use due to the existing circumstances.

8.5 Summary of the analysis

This chapter started with discussing the policy models related to innovation and industrial development in the semiconductor and biotechnology fields (section 8.1). As has been demonstrated, the emphasis of contemporary Taiwanese industrial and innovation policy has been: (1) to create innovation and industries here and now; (2) to use novelty as a main source of new economic resources; and (3) to linearly transfer research results from science to the industry.

The picture from a policy perspective was followed by the analysis of the three empirical cases from a resource interaction perspective (sections 8.2–8.4). From the analysis of the resource structures, how economic, organizational and technological effects are created through the constant recombination of resources, especially new ones, with existing structures have been investigated. Table 8.1 below summarizes the analysis with respect to the three settings and also the three empirical cases. These findings will serve as a basis for the discussion in the subsequent chapter.

Table 8.1 Three different settings in three different empirical cases

Settings	Semiconductors	Vaccine	Liposome
Developing	The developing structure built up by research institutes and policy organizations. These were able to connect to established knowledge sources from academia as well as business. Development decisions were made close to the producing and using settings. The developing structure worked with mature solutions. Academic research was not directly involved.	Taiwanese policy very active in directing the developing structure, made up of a public research institutes and government funded research facilities. A well-known method was used to develop the vaccine, but no relationships to established vaccine developers or producers. The developing units were inexperienced and the government does not initially build on established resource structures.	The developing units have strong connections to academic units, and to established producer-user structures (built up over three decades). The developing structure wanted first to use the research results for academic activities, but when a drug was to be developed the transition went quite quickly because of the experience and connections to established business structures (which had liposome business).
Producing	A new producing structure was built up in Taiwan over a decade, with the help of established producing structures from abroad. There were large costs for production facilities and only government was willing to sponsor this project. The facilities were not state of the art and the technologies being developed and produced were based on mature solutions. After a decade the producing structure had only small customers and after two decades the producing structure gained advanced users as customers.	Initially no producing structure in Taiwan. Government funded the producing structure and built it up with help of existing research institutes. These structures had little experience in vaccine development and production. After a decade and much government commitment it is possible to produce vaccines, but no vaccines yet to be fully developed. Few other local producers, currently in the business mainly because of government support.	A producing structure already existing. The developing structure and producers could combine resources which were complementary. The producing structure somewhat inhibited innovation due to the large investments already made in existing structures with extensive producing networks and marketing channels. Larger pharmaceutical companies acknowledge the potential of liposome drugs but want to wait until they see improved R&D results and milestones.
Using	The early users were Asian electronics manufacturers. But large advanced users with extensive resources, had connections to the Taiwanese market early. The demand for Taiwanese semiconductors was created through interaction between established producer-user interfaces and developing structures.	The government as the user, will distribute to hospitals and clinics et cetera. Policy wants to build up a vaccine industry. The government a very demanding customer. Very specific in planning the overall development of the network, sponsoring producing as well as developing structures.	A using structure is deeply embedded in the Taiwanese context. The using structure impeding novelty, due to existing investments and health care system. The users do not want novel products, because of economic reasons, e.g. they cannot get government reimbursement.

The view which has been advanced in this dissertation is that the empirical settings, from which resource interaction is investigated, are central to explaining innovation and the emergence of industries. Depending on the setting, the goals and rationale of how resources are used and combined are different. Therefore, studying how the settings interact and how they can benefit but also conflict with each other is an important aspect of increasing the understanding of the empirical problem identified in the introductory chapter, i.e., why new (science based) solutions have difficulty becoming innovations.

What has been clear from the analysis is that just because something new is developed or invented, no matter how innovative it is, does not mean it will automatically be produced and used in a business setting. Hence, in order to understand these processes we need to examine the specific rationales which drive activities in each setting, including the interaction between them as they make up a larger network of resources. As the empirical findings show how value is created in the larger network of resources, as well as in the developing, producing and using structures, is a complicated process which has few traces of linearity. What is considered innovative in a developing setting does not necessarily create value in a using setting. If it does not the embedding of the new is less likely.

What has been suggested in the analysis hitherto is that the using structures look at technical as well as organizational features. The producing structures have to consider the economic issues of production as the producers are more reliant on the users, paying customers, than the developers are. Although there are differences the structures need to benefit from each other for innovation to come into being, that will say to become developed, produced and used. These issues will be discussed in the next and final chapter.

CHAPTER 9
SCRUTINIZING A POLICY AMBITION TO MAKE BUSINESS OUT OF SCIENCE – LESSONS LEARNED

This chapter will summarize and discuss the findings of this dissertation. It will be done in three sections, where each section considers one of the three research questions identified in Chapter 1.3.

a) In the first section (9.1), the general the research scope of this study is addressed. This is followed by a discussion of the main characteristics of the Taiwanese policy recipes for innovation and industrial development, including the expectations which they have raised.
b) In the second section (9.2), the main lessons of the empirical cases from a resource interaction perspective are presented. What is discussed are:
    - The three settings, exemplified empirically through resource structures related to developing, producing and using activities.
    - The interfaces between resources in the different settings in each of the three cases. This provides pictures of how innovations come into being and how industries emerge.
c) In the third section (9.3), a comparison between the policy picture and the picture formed by the resource interaction perspective is made. Three key issues are identified, which function as the basis for a discussion of policy implications. This section is concluded by identifying areas for future research.

9.1 The research scope revisited – Contemporary policymaking

A focus of contemporary industrial policy has been to create innovation and new economic resources out of scientific research. As pointed out by Edquist (2001) among others, various research and innovation strategies have nowadays become the de facto industrial policy. Seeing that governments all over the world have aimed their attention at increasing national

scientific output for transfer to industry, more emphasis has also been directed towards studying these ambitions. In this context, a commonly noted observation is that efforts to transform new scientific discoveries into value-creating innovations have not generated the results that have been expected. This is most clearly demonstrated by the idea that there exists a *knowledge paradox* (e.g. Soete, 2002; OECD, 2005; Audretsch & Keilbach, 2008). While it is often voiced in policy analysis that the amount of new high-tech products do not correspond to the increase of investments made into R&D, some authors (e.g. Dosi et al., 2005) however argue that these claims are unfounded.

Irrespective of whether a knowledge paradox exists or not, this study has shown that there is relatively weak evidence that current research and innovation policies affect the targeted components of the economy the way they are designed to. For example, even if it is possible to increase patent output or the number of start-up companies, through directed government funding, the long-term and more indirect economic and technological effects of such measures are difficult to foretell. Although this has been acknowledged as a problem among policymakers, the same strategies continue to be implemented with large commitment and optimism from governments. This has resulted in policy efforts at times almost appearing as some form of modern alchemy. Nonetheless it is clear that the often serendipitous, but still managed, nature of innovation and industrial development poses several challenges to the policy attempts to create innovation through a transfer model with linear components. Given this background I argue for the necessity to scrutinize certain contemporary industrial and innovation policies and the way they are designed to affect innovation and industrial development.

Hence the focus has been to study how innovations come into being and how industries emerge, by investigating how resources interact in and between developing, producing and using settings. This research design has been based on an understanding that these interaction processes exhibit strong non-linear traits where, for instance, developed solutions sometimes stem directly from scientific research and at other times directly from industry. The origin of what is developed has not been of primary interest, however, nor has the potential of science to enhance societal and economic development been in question. Instead it is the processes of how resources interact and create value all the way from development to production and thereafter use which are at the center of attention. Approaching the empirical question from a resource interaction perspective provides a sharp contrast to the policy model based on stylized assumptions which view development as starting from scientific research and thereafter moving to midstream application and lastly to industrial use.

The empirical focus of this dissertation has been the Taiwanese government's efforts to create a biotechnology industry, in the wake of Taiwan's economic success in the semiconductor field. As discussed, the semiconductor industry has often been referred to as a creation of public policy. In the 1970s when the government decided to promote semiconductor research and business there was basically no industry related to this area in Taiwan, but three decades later the Taiwanese semiconductor industry was ranked the fourth largest in the world. This impressive growth has garnered an interpretation of its development that has become a role-model on how to build new industries in Taiwan. The main components of the model have been the creation of public research institutes, public provision of R&D, technology transfer, the establishments of science parks and active government guidance. Since 1995, this template has been applied to establish a biotechnology industry in Taiwan. The Taiwanese biotechnology endeavour has, however, been considered a failure by several commentators, quoting, for example, the modest revenues of local companies, lack of innovative capacity, and limited use of novel technologies in the industry, as reasons behind the disappointment. Another often stated opinion is that biotechnology is too different from semiconductors and that to expect a similar industrial development path is not possible.

This study does not go any deeper into these issues further than to acknowledge that the two technological fields are different and that income in the Taiwanese biotechnology industry has been modest compared with the revenue generated in the semiconductor industry. Apart from this, my stance is that there are other more relevant concerns which need to be addressed, as is evident from the findings provided by this dissertation. The main point I want to bring forward, and emphasize in the larger debate is that the current industrial and innovation policies in the biotechnology field in Taiwan, to a large degree modelled on the semiconductor industry, has created expectations that are highly unrealistic. The Taiwanese innovation and industrial development model is clearly oversimplified. I do not criticize the simplicity of it per se, instead it is the underlying assumptions which are in question, for instance, those reflected in the government's interpretation of how the semiconductor industry emerged.

The policy recipe to success bringing forward unrealistic expectations

The Taiwanese recipe to build up high tech industries is a construction made in retrospect based on a mix of empirical observations and model-based assumptions. In the template's application to create a biotechnology industry additional stylized facts have been added where the most pronounced ones are related to the understanding that frontier science and innovation are main determinants of economic wealth creation. But as this dissertation has shown several important empirical factors which condition the emergence of industries and innovations have been neglected in Taiwanese policy plans. Considering that there is a widespread opinion that the Taiwanese policy attempt to create a biotechnology industry has been a disappointment, there is an increased need to put the "forgotten" empirical conditions to the forefront. These conditions will later in this chapter juxtapose the policy view and provide a basis for the scrutiny of past developments, i.e. the semiconductor industry and its associated development model and also current Taiwanese policy measures to promote biotechnology.

From the empirical study it was understood that there are three expectations that have strongly formed contemporary Taiwanese policymaking. These were discussed in chapter 8.1 and were as follows:

- An emphasis to create innovation and industries here and now
- Novelty and new discoveries as main determinants of innovation
- Innovation as largely an issue of transfer

This dissertation argues that the expectations mentioned above are more grounded in high hopes and stylized facts rather than profound empirical experiences of industrial development. Consequently the perceived failure or disappointing results of the biotechnology industry is a symptom of these unrealistic expectations (which we will come back to later). The notions of failure or success, largely dictated by the expectations of what will happen within a certain period of time, has however not been of particular interest in this study. Instead of labelling biotechnology as a failure or a success I have focused on studying and describing the empirical processes through which innovation and industries emerge. Hence let us continue with discussing the empirical characteristics of resource interaction which are general whether we are talking about biotechnology or semiconductors.

9.2 The interaction of resources

As was noted in chapter 2, network-like structures are an integral part of the business landscape where companies interact with other companies and organizations in order to create value. Without making any judgement about whether network-like structures are good or bad, this dissertation has aimed to describe and understand their role in the processes where industries and innovations come into being. The benefits of network-like structures are, as mentioned earlier, higher efficiency and innovation, but networks do not only have benefits, they are also subject to conflicts. For example, actors have different goals and the settings in which resources are combined are driven by various rationales. These in turn influence the interaction, the embedding and use of resources. By approaching empirically how innovations are developed, produced and used in an industrial context, I have provided a complementary picture of how of how existing business structures both can facilitate and hinder science-based resources to become embedded – this picture also has theoretical implications.

Innovation and technological development have been studied by numerous scholars in the IMP tradition (e.g. Laage Hellman 1989; Waluszewski, 1989; Lundgren, 1991; Håkansson & Waluszewski, 2002). The majority of this body of work has underlined the importance of material and immaterial investments in place in the business landscape. Rightly so, as noted by Von Hippel (1988) among others, it is within existing business structures that much innovation occurs, or as Rosenberg (1982, 1994) demonstrates, in the interface between producers and users. However, in contemporary policymaking it is the creation of innovation stemming from science, i.e., solutions which are often developed rather far away from close interaction with existing material and immaterial resources structures, that is emphasized. Thus it is of interest to increase the understanding of how new solutions from a developing setting are embedded into existing producing-using structures. From this study there are several contributions to the understanding of this matter. The findings are based on two discussions, first, an understanding of the various settings and, second, on the interaction between them.

An understanding of the different settings

As was demonstrated in the empirical material, three settings are necessary for innovation to come into being, namely development, production and use. Although these are connected when it comes to a single innovation, the resource structures related to these activities (i.e., the settings) often exist in parallel over time and in different spaces. What is important to recognize is that the three different settings follow different rationales. The characteristics of each setting are summarized below (see also Table 8.1).

The developing setting: Development of new solutions is often done in R&D laboratories at companies, universities or research institutes. These developing activities and their related structures are referred to in this study as a developing setting. The developers in the empirical study are heavily geared towards "applied" research, often meaning research conducted at research institutes or company laboratories. As substantial costs are often involved in developing new solutions, the funding for such projects often comes from public sources, which was the case in both the semiconductor and vaccine cases. Although the producing-using structures clearly have connections to academic research, as shown especially in the liposome case (for example, universities are an important source of educated personnel and knowledge), research results from academia are frequently considered as unsuitable for commercial development. This relates to the notion that academic research is primarily concerned with the development of cutting-edge science, that will say the search for novelty and the undiscovered. Thus the connection to production and use is often quite vague in these settings. However, closeness to producing and using structures does not necessarily result in the use of developed solutions in the existing producer-user structures. Even with "applied research" there are obvious distances to producing and using structures, as the activity implies the search for something new. Hence what the empirical findings have illustrated is that, in the developing setting, whether conducting basic or applied science, very often goals clash with those of producing and using settings.

The producing setting: The picture from a producing perspective is different from the developing perspective as there are more economic pressures. In the producing structures we find mainly business actors but also research institutes and policy. These structures are often characterized by large investments in material resources. In the empirical chapters it was

exemplified how production facilities were built-up from scratch in the vaccine and semiconductor cases. The investments in money and time were considerable, thus putting pressures on producers to create revenues. Thus the importance of developed solutions which fit with the standards of these production facilities is necessary. The closeness between the developing and producing structures was helpful in these cases. In the liposome case the situation was somewhat different as there were no prior relationships between developer and producer. This put a greater emphasis on the fit of what was developed as the producing structures were already in place. The reason is that producing structures are often reluctant to impose larger costs and time-consuming changes on the existing structure. Hence a critical issue is whether earlier investments can be utilized. The advantage of having an existing structure of producing resources is obvious, e.g. few additional investments in material resources are required. To sum up, it has been illustrated from the empirical material that the producers are concerned with the return on investments and the economic issues are considered to a large extent. However, having production capabilities does not equal any use, this requires closeness to users, as these are the ones paying for what is produced. Therefore the existence and interaction with users, where revenue comes from, is imperative.

The using setting: Any innovation that comes into being also by definition has a use. Thus the use of a developed and produced solution is an essential part of the value-creating process. In this study we refer to users as customers, whether it is companies, policy or academic users willing to pay for a new solution that has been produced. As has been evident from the prior analysis, the using setting is concerned with how the innovation can fit into the existing structure of investments and create value. In this respect resource combination becomes a relevant issue. What is concerned is how the related interfaces are affected by the introduction of something new. Hence the features of something developed depend on the structure of where it is to be used. In this respect novelty for example, does not necessarily contribute positively to value creation. This was quite obvious in the liposome case, where new novel products did not fit into a structure which rewards the production of generic products. In the semiconductor case, the importance of creating value for existing investments was also clearly reflected by the advanced semiconductor companies willing to come in only as they saw an opportunity to increase the value of their established resource structures.

An understanding of how innovations come into being and industries emerge

In order for innovation to occur and industries to emerge, the developing, producing and using settings have to be somewhat connected. Thus we need to understand the larger networks in which resources interact and are being combined. The larger network-like structures of producing, using and developing interfaces as mentioned, can be characterized by close interaction or be very distant from each other. But irrespective whether the structures are close or not, they all have to take advantage of existing material and immaterial resources in different settings. This means that the settings will be interdependent at the same time as they have partly conflicting interests. Including the previous discussion, which illuminates the intricacies of combining resources from different settings, we can understand that if combining resources within established structures is challenging, then introducing something new from outside these structures should be even more difficult. This point is consolidated and explained through the following discussion of some specific notions related to resource interaction. From the analysis of the interaction between resources in each of the three cases (see sections 8.2–8.4) three main lessons can be derived, these are summarized below.

Resource interaction is non-linear and occurs in different times and spaces: That a new solution is all of a sudden developed and thereafter instantly produced and used does not seem to be common, as demonstrated by the empirical material. An important lesson which has been accentuated in the analysis is that it is not single events at a certain time and place which create innovation and the emergence of industries. Instead these processes are the result of the planned or unplanned combination of various resources in different settings that might be directly or indirectly interfaced with each other. Given this understanding, the emergence of industries and innovations can be seen as a myriad of different resource combinations over an extended period of time and in different places, where the number of permutations of possible resource combinations is endless.

As stressed by Waluszewski (2004), to allow for *variety* is also a prerequisite for new technological and economic effects to be created. But in this view there is inherently more uncertainty to innovation as a clear start and end is not entirely obvious. This was illustrated in empirical material where development, production and use often occurred simultaneously. For example, the emergence of semiconductors happened without following a linear path

where the innovation process required first R&D, then production and finally use, at consecutive separate stage. It is instead clear how use-production-development were happening concurrently, where developing structures emerged in relation to already existing using and producing structures. With the assistance of established knowledge sources, it took more than a decade to establish research and development capabilities. The producing structures were built up over an even longer period with close contact to users. These users had an established presence in Taiwan already in the 1960s and, although they were not active at the time, resource synergies were created. The emergence of a Taiwanese semiconductor industry was thus a result of combinatory efforts stretching over at least three decades.

When it comes to biotechnology, which is in general considered a complex technological field, resource combinations in different times and places would arguably be common. A picture of this non-linearity was also reflected in the liposome case, where the development started in academia, and then became used in a business setting before returning back to the academia in a Taiwanese context. In the vaccine case the challenges to create development and production here and now were particularly obvious. The three empirical examples illustrate that the resource combinations are planned by the actors involved but not fully controlled by any actor. Moreover the emergence of industries and innovation is a trial-and-error process where variety and time are important components.

The new is always introduced in a context and builds on something already existing: The findings from the empirical study suggest that the emergence of the semiconductor and biotechnology industries in Taiwan was the result of the interaction between various resource structures extending beyond spatial, organizational and technological borders. As has been touched upon above, there were no single mechanisms triggering the emergence of an industry overnight. However, an important factor for value creation was the ability of different actors to take advantage of what has already been created in other structures. In this respect the Taiwanese government's efforts to create space for Taiwanese organizations and companies in an international network, covering development, production and use, has been an interesting aspect to study.

What is implied is that resource combination means building on what already exists. Hence the notion that there is always something to build on is imperative to elaborate. In the empirical material the importance to build on existing resource structures has been clearly illustrated. New resources are always combined with other resources and existing structures. Connecting to existing structures can both be advantageous and also have disadvantages. For

instance, in the liposome case, when the developing structures were able to combine complementary resources with existing producers it created synergy effects which were beneficial for both parties. In the semiconductor case, the interfaces to existing structures also proved beneficial. For example development of semiconductors in Taiwan was not based on what was traditionally considered as desirable in research, that is to say cutting edge technology, but was driven by R&D on a mature solution that had already been tested in existing producing and using settings. Similarly this was done in the vaccine case, where the method to develop and produce a Japanese encephalitis vaccine was also based on an old production method. However, due to inexperience of developing units and conflicts between various structures, few benefits were created. Thus an understanding derived from this observation is that the *heaviness* of interacting resources (Håkansson & Waluszewski, 2002), referring to the importance of a resource, is something which does not automatically emerge. This was clearly evident in the vaccine case, where interfaces between various resource structures were created but with very little actual interaction occurring between the interfaced resources.

The using structure is important in creating demand and shaping features of resources: As has been discussed, there are three settings to take into consideration when investigating how innovations come into being, i.e., development, production and use. Each one has its own function to fulfil, but they also need to benefit from each other. What is in focus and has been clear in this dissertation is the need to understand how the using structure creates demand and shapes the features of what is developed and produced. As the empirical study illustrated, users are not passive and there are direct as well as indirect effects of interaction. For example, in the semiconductor case, the foreign companies, after they set up Taiwanese subsidiaries, provided local employees and suppliers with education, knowledge and technology, which would later be of importance. Already from the 1960s new local companies were started in the wake of the foreign investments. What was in creation was the development of a producer-supplier network which continues until today, where semiconductors became an extended business activity due to already established business relationships. Thus these interfaces brought forward knowledge and also various solutions which could benefit the Taiwanese industry.

The using setting does not only contribute with positive effects, however. In the liposome case it was shown how the using structure became a constraint for the developing structure. The using structure inhibited the development of novel liposome drugs due to

investments already made and various regulatory factors et cetera. Similarly in the vaccine case, the conflicting goals of the using structure with developing and producing structures impeded the development of vaccines. Hence, how innovations come into being is an issue of interaction between development, production and use. Users are active and demanding, and that is a large reason why new solutions often do not find an economic use. Furthermore, users are sources of knowledge for developers and producers, but even though relationships exist they are not necessarily customers unless there are clear benefits for the using structure through a fit with existing investments. Thus this suggests that the study of embeddedness of new resources into using structures is of relevance, as the issue of how the new solution can be embedded in a using structure is critical for an innovation to come into being.

9.3 A comparison between the two policy and interactive perspectives – Policy implications

What is then the relevance of advancing an understanding of the three different empirical settings, as well as explaining the nature of the interaction between resources in the three different cases? In this section, the policy ambition of creating innovation and industries will be confronted with the lessons learned from the resource interaction perspective. From this comparison, three main conflicts are identified, which will form the basis for a discussion on policy implications.

Conflict 1: Innovation and industrial development here and now – Resource combination occurring in different times and spaces

The ambition to create industries and innovation *here and now* is obvious in contemporary innovation policies. This was exemplified in chapter 5, where the Taiwanese government's ambition to establish new industries was presented. As shown, Taiwanese policy has aggressively promoted different parts of the economy ranging from upstream to midstream and downstream sectors. The efforts to build up developing and producing structures have clearly been concentrated to specific regions. In addition, by providing funding and a supportive infrastructure, such as science parks and intermediary research organizations aiding transfer, the expectation of Taiwanese policy has been that new high-tech solutions and industries can emerge promptly. Hence, the template used to achieve the goals of industrial

development and innovation is simply stated: To find a piece of land, often in close proximity to research units, and establish a science park where new companies can locate. Then speed up and enhance the process of transfer of new resources from scientific units to industrial users, by having research institutes serving as midwives.

The Taiwanese policies aimed to create innovation and industrial development do, however, put the importance of the various resources interacting and the time component in the background. Even though the tale of the semiconductor industry springing up from nowhere, through the transfer of external technology, is an attractive story to tell, the results of the recipe's application in reality have not been as enchanting. As the analysis of this study has demonstrated, the Taiwanese semiconductor industry was clearly not an overnight success. Furthermore, measures of "success and failure" in certain times and places are arbitrary constructs dependent on the measurements chosen. For example, had the semiconductor industry been evaluated in terms of economic output, after two decades it would, like the biotechnology industry, be considered a disappointment, especially considering the large amount of resources the government had invested up to that time. What should be emphasized is that that the emergence of the semiconductor industry and innovation was a process spanning several decades. From the establishment of the first foreign electronics companies until local semiconductor business practices were established, three decades had passed. Moreover in this time resources from various places and organizations had been combined. Consequently innovation and industrial development is not an act guided by a sole actor or catalyzed through a single event, such as the establishment of a research institute. This complexity of how resources are combined has been exemplified in each of the three empirical cases.

With regard to these lessons, we can conclude that space and time are valuable conditions for innovation and the emergence of industries. This is not in a way that less is better, but rather that time and a multitude of spaces allows for different resource combinations to occur, allowing resources to be re-modelled and confront each other. Thus the expectation that tangible innovations based on new advanced knowledge can be created at a specific place within a few years is likely to result in disappointment. Development, production and use processes are not always straightforward. Knowledge of possible resource combinations is created through trial-and-error processes and requires interaction in different times and spaces. The need for this variety directly contradicts the possibility of creating innovation and industries here and now.

Policy implications: What has been proposed brings difficulties to a linearly designed place- and time-dependent innovation template. This is most vividly illustrated by the policy attempts to create network-like structures. As Ford et al. (2002) argue networks are too complex to create. In the context of this study, the reasons for this are that it is difficult to know which actors or resources should be included in complex innovation processes a priori. Network-like structures are not controlled by a single actor, and creating interfaces between various resources "artificially", through a number of policy incentives, does not automatically lead to heavy interaction. From this understanding an important issue to consider is – What happens when policy is trying to create network-like structures in order to achieve innovation and economic growth?

As shown in this study, to create network-like structures "artificially", can hinder innovation. Controlling processes, which are highly unstructured in a structured way can impede the combination of resources, by disallowing for variety. In addition, when conscious attempts are made to create networks, much support is usually given to pre-identified winners. The networks of development, production and use are, however, often much larger than those identified by the government. The support to already established structures and actors, has its benefits but it creates a system where funding mostly goes to the ones that already have, irrespective of whether they are the most suited for those means. In addition in such a system actors also start to rely on government funding as a major source of financing and a large amount of time is directed to acquire more government sponsorship. This can function as an impediment to efforts at wider resource combination. Furthermore strategies to find national winners do not often support the unknown, from which new opportunities could arise. Although the role of the government as a network actor should not be neglected, policy should not primarily focus on identifying winners based on stylized facts, and dictate how they should interact. Instead what is argued is that policy should create room and opportunities for interaction on a broader level, rather than artificially building structures and expecting innovation here and now.

Conflict 2: Emphasis on novelty – Building on what already exists

The emphasis on novelty as a main source of innovation and industrial development has strongly characterized contemporary Taiwanese policymaking. New science based solutions and discoveries have been considered as something intrinsically positive and the basis of

many innovations. However, there are a number of different challenges which need to be addressed with this view that have been evident in this study. What is missed by concentrating on novelty per se is the conception that the new still needs to relate to existing structures. This view closely resonates with Schumpeter's (1934) notion of *Neue Kombinationen* (new combinations) of existing knowledge as the source of innovation. Although novelty per se is not necessarily unusable, there is a need to consider that creating new solutions and embedding them into established structures is largely an issue of fit with already existing resource structures of both physical and organizational character.

Thus an important lesson is that new solutions are always combined with existing resources that in turn have interfaces to other resources. Since development, production and use is the successive embedding of interfaces in relation to each other over time and different organizational and geographical borders, interdependencies are created over a larger structure of resources. These resource structures are characterized by stability and a resistance to change. Through this observation we have our main problem, as novelty does often not fit very well into established organizational or physical structures. The more novel a solution is, the more difficult it will be for it to fit and embed into established structures, due to the larger costs for the existing structures to combine the new with the old. This understanding also touches on the earlier discussion that innovations are not developed out of nothing. If this was the case we can assume that it would require much time and effort to connect and embed new solutions into existing resource structures in order to also create production and use.

The expectations on novelty per se, as a deciding factor, provide a stark contrast to the empirical material, where actually much of the "novelty" was built on mature solutions. With mature solutions there are usually already interfaces to existing producing and using settings. This creates benefits in terms of, for instance, closeness to markets or understanding of development processes et cetera. Therefore, as exemplified through the three cases, to build on what already exists is a salient characteristic of resource interaction. The above argumentation suggests the importance of studying the effects of introducing something new into existing structures. As mentioned, novelty has no value for existing resource structures, unless there is a value for investments already made, first then can it be embedded.

Policy implications: From the above discussion it is implied that we need to look beyond the view that novelty, frequently represented by scientific research in policy formulations, is the main determinant of innovation. Consequently increasing the number of patents or scientific publications is not a good measure or guarantee of innovation. Of course policy incentives to

increase R&D do create development in certain directions, but to focus on novelty per se can be somewhat misleading. Instead it is necessary to go beyond the analysis of direct metrics and also look at value-creating processes and especially the indirect effects created. Because the empirical world exhibits strong traits of non-linearity and interdependence, policy analysis should put more emphasis on how the new can be integrated with what already exists. It is especially important to consider the need for a using structure when innovation comes into being, which is also the next point of interest.

Conflict 3: Innovation as a matter of transfer starting with science – The using structure deciding the embedment

As was shown in the empirical chapters, the spotlight in contemporary Taiwanese policy plans has been on creating a proper technology transfer system. Focus has been on R&D as a determinant of innovation, and on the diffusion of scientific research to the industrial world. The findings stemming from such analyses are usually that knowledge produced in the research segments of the economy (e.g. universities and research institutes) are not absorbed and used by the downstream segment (the industry). With such a view the using structure is generally considered to already exist and be readily waiting to absorb whatever is being developed and produced. As the issue of use has been moved to the background in favour of an analysis of how new solutions are developed and transferred to producing settings, an important part of understanding innovation has gone missing. The emphasis that innovation is an issue of direct transfer, however, conflicts with the empirical findings of this study. What the findings of this study have shown is that embeddedness is largely decided by the using structure. Consequently there is a need also to examine how new solutions that are developed become embedded using structures. That will say there is a need to understand the whole process from invention to innovation, i.e., from development to production and use.

What has been suggested, similar to Von Hippel's ideas (1988, 1998), is that users are not passive receivers of whatever is developed and produced but are quite active, sometimes even in the developing stages of innovations. Neglecting such a salient feature of how value is created is not helpful for policymakers as the using structure is very much an active part of the economic landscape and cannot be excluded from an analysis. Without valuing whether it is good or not, understanding the role of using structures is imperative. Focusing solely on the development and diffusion of science, whether basic or applied, does not tell us much about

how it will eventually be used. Instead we need to take into consideration issues why science per se has no value for (business) users, by starting from the using structure.

Policy implications: What has been suggested is that the three settings are very different. What is considered valuable in the developing setting is different from what is valued in a using setting. When these boundaries are blurred (especially between science and business) it is no guarantee of innovation and new problems are created, as this study has exemplified. Even when developing structures are beginning to act more like business structures, it is still difficult to introduce new solutions. Although the three settings need to benefit from each other for innovation to occur, each setting has its own rationale. Therefore there should not be a focus on harmonizing the goals they have and the activities they conduct (there are more factors involved than just making them the same). In this context it is important to understand the using structure and an analysis could reduce risk for policy investments. As has been described, it is difficult to bring new things into the using context, especially if the new solution is intrinsically different from the current structure.

Epilogue and Future research

While government action can have an important role in the emergence of new industries, it also sets in motion a myriad of other processes. As has been clearly reflected in the empirical study, what the exact outcome of policy direction will be is extremely difficult to predict since it is contingent on the actions and reactions of others. Therefore when "artificial" innovation networks are created by the government, it is not easy to get these structures to function the way government policies have designed them to do. A simple reason is that, in network-like structures, each actor has its own view of how resources are to be used and creates a unique combination of material and immaterial resources, over time, which in turn is embedded into other resources structures.

An important observation made in this dissertation is that developing, producing and using settings and the actors representing these always have, at least partly, different rationales. Thus what is beneficial in producing and using settings is not necessarily beneficial in a developing setting, and vice versa. This conclusion opens up for important research issues with concern to the role of policy. For example, what happens when activities guided by public policy concentrate on adapting developing structures to the requirements of producing

and using settings? Or, what happens when focus of policy is aimed at adjusting producing and using settings, so these can embed new solutions from the developing setting? Whatever choices are made there will be consequences, economic as well as political and social. To study these consequences, negative or positive, is imperative not only from business and governmental perspectives but also from research policy and democratic perspectives. This understanding outlines an important topic for future research.

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APPENDIX 1: Mainstream ideas of economic development focusing on production and diffusion of knowledge – From traditional economics to innovation systems

In this appendix some of the theoretical approaches that have been influencing contemporary policymaking will be discussed. Some of these are discussed below in the quote from the OECD.

> OECD analysis is increasingly directed to understanding the dynamics of the knowledge-based economy and its relationship to traditional economics, as reflected in "*new growth theory*". The growing codification of knowledge and its transmission through communications and computer networks has led to the emerging "*information society*". The need for workers to acquire a range of skills and to continuously adapt these skills underlies the "*learning economy*". The importance of knowledge and technology diffusion requires better understanding of knowledge networks and "*national innovation systems*". Most importantly, new issues and questions are being raised regarding the implications of the knowledge-based economy for employment and the role of governments in the development and maintenance of the knowledge base (OECD, 1996: p3).

As can be noted from the quote some of the major theoretical concepts which have influenced policy in developing economies and industries at both regional and national levels have been traditional economics and the innovation system concept. In this section I will provide an overview of these general approaches and other related ideas starting with the view of economics followed by the innovation system approach, triple helix and cluster approaches. It is not the aim of this chapter to provide a comprehensive overview of all the theories and concepts that influence policy in making decisions related to industrial development and innovation. What is provided is an outline of a selection of theories and their main ideas, which governments and policy-organisations such as the OECD and the UN among others frequently reference to.

Traditional economics & New growth theory – Introducing technological change and knowledge as determinants of growth

As Paul Romer (2007: p1) describes "economic growth occurs whenever people take resources and rearrange them in ways that are more valuable. […] To create valuable final products, we mix inexpensive ingredients together according to a recipe". In economics, recipes to growth and development are commonly studied through the field of *Development Economics*. The beginning of this field can be attributed to Harrad (1939) and Domar (1946) which independently of each other developed a framework that later became known as the Harrad-Domar model. In this model economic growth is a function of two factors, the savings rate and the productivity of capital. In support of Harrad and Domar's ideas *The Linear Stages of Growth Model* was introduced in the 1950s by Walt Whitman Rostow (1952, 1960). He identified five different growth stages of an economy where the accumulation of capital and savings were the major factors to development. However a number of studies soon showed that capital accumulation and savings rate could only explain a country's growth rate partially, there was quite a large residual which was unaccounted for.

As a response Robert Solow introduced in the late 1950s, in a series of articles, technological change as an additional determinant to economic growth.[102] For example in a paper from 1957, *Technical Change and the Aggregate Production Function* Solow showed that 90 percent of the economic growth in the US in the late 19th and early 20th centuries could be derived from technological change. Although not explaining where the change originated from it was identified as the major source of growth. Of course leaving a factor with such a high explanation rate unaccounted for and taken as given was something disturbing.

A movement to establish a new research area set out to describe how technological progress brought forward economic development was created. Based on for instance the works of Paul Romer in the 1980s and 1990s *New Growth Theory* was eventually developed. This theory emphasized that economic growth is the result from the increasing returns derived from new knowledge. In comparison with physical goods knowledge is possible to increase elastically, giving it unique properties. Therefore knowledge provides the economy with opportunities to grow beyond what can be achieved with finite resources (Romer, 1986, 1990). The development of new growth theory led to a paradigmatic shift in the understanding of

[102] Around the same time Jewkes, Sawsers & Stillerman (1956) had in a study suggested that economists were generally ignorant of technological change.

why economies grow. It emphasizes the processes where knowledge is created and diffused as the reasons to why nations and firms grow (Cortright, 2001).

The diffusion of innovation - Innovation Systems

The economic growth theories have been instrumental in recognizing technological change and knowledge as drivers of economic development. It is through the understanding provided by these theories which the premises of the knowledge based economy stem from. Focusing on this subject, various approaches and theories have been developed in related areas such as the study of the diffusion of innovation.[103] Among these, one of the major concepts adopted by contemporary policymakers today is the *Innovation System Approach*.[104] The frameworks relate to analysis of bounded phenomena at different levels such as local, regional, national or sectoral (Lundvall, 1992). The term "innovation system" was first framed in Freeman's study from 1988 of the Japanese economy. However the concept of the innovation system was introduced by Lundvall in *Product Innovation and User-Producer Interaction* (1985).

The systems of innovation frameworks have become an important alternative tool to traditional economics in guiding policymakers on making decisions concerning science and technology policy, and economic development. According to the OECD (1996: p12) the national innovation system approach has received analytical importance due to the following three factors: 1) the recognition of the economic importance of knowledge; 2) the increasing use of systems approaches; and 3) the growing number of institutions involved in knowledge generation.

In economics, technology related analysis focuses on the inputs and the outcomes created in the economy. Criticism was however early aimed at this determinism and black boxing of technological development (see e.g. Rosenberg, 1982; or Lundvall, 1988). In the innovation system approach a focus is directed towards how innovation occurs, that is to say how inputs are translated into outputs as a result of various forms of learning (Lundvall, 2007). As described in an OECD report (1997: p9) "innovation and technical progress are the result of a complex set of relationships among actors producing, distributing and applying various kinds of knowledge. The innovative performance of a country depends to a large extent on

[103] The study of innovation and its relevance for economic growth was already established by Schumpeter in the late 1930s. (See Schumpeter, 1934)

[104] The innovation system approach was developed as a reaction to the problem of neoclassical economics to describe technological change, and its inability to provide detailed policy guidance in the areas of science and technology. (Lundvall 2007)

how these actors relate to each other as elements of a collective system of knowledge creation and use as well as the technologies they use". Commonly understood is that the analytical focus is on the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge. (Lundvall, 1988)

Spatial Agglomeration - Clusters

In the innovation system approach it is the ecology of actors within a system, which through interaction create and diffuse innovations, that is of interest. A comparable concept is the cluster framework proposed by Porter (1990). Cluster analysis has been applied and used extensively in both policy and academic circles (Teigland et al., 2004). Similar to innovation systems it does not have a universally accepted definition. A definition which is used by Porter (1998) is:

> Clusters are geographic concentrations of interconnected companies and institutions in a particular field. Clusters encompass an array of linked industries and other entities important to competition. They include, for example, suppliers of specialized inputs such as components, machinery, and services, and providers of specialized infrastructure. Clusters also often extend downstream to channels and customers and laterally to manufacturers of complementary products and to companies in industries related by skills, technologies, or common inputs. Finally, many clusters include governmental and other institutions-such as universities, standards-setting agencies, think tanks, vocational training providers, and trade associations- that provide specialized training, education, information, research, and technical support.

Teigland et al. (2004) identify four assertions on which the literature on clusters are based on. These are as discussed by the authors as follows (Teigland et al. p19-20):

> First, in today's knowledge based economy, the ability to innovate is more important than cost efficiency in determining the long-term ability of firms to prosper. Innovation is defined broadly here as the ability to develop new and better ways of organizing the production and marketing of new and better products (Porter, 1990; Lundvall, 1992; Nelson, 1993; Nonaka, 1994; Grant, 1996). This does not mean that cost considerations are not important, but simply that the combined forces of the globalization of markets and the deepening divisions of labor make it increasingly difficult to base a competitive

position on cost-advantage only. Second, innovations predominantly occur as a result of interactions between various actors, rather than as a result of a solitary genius (Håkansson, 1987; von Hippel, 1988; Lundvall, 1992). This fits with a Schumpeterian view of innovations as new combinations of already existing knowledge, ideas, and artifacts (Schumpeter, 1934). Additionally, most innovations are based on some form of problem solving in which someone generally perceives a problem and turns to someone else for help and advice. In an industrial context, these interactions often follow the value chain. A firm facing a particular problem turns to a supplier, a customer, a competitor, or some other related actor to get help in specifying the problem and defining the terms for its solution. From this follows that the level of analysis for understanding the processes of industrial innovation and change is some notion of an industrial system or network of actors carrying out similar and related economic activity. The cluster is basically then an attempt to conceptualize an industrial system. Third, and this is where "geography" enters the picture, there are a number of reasons why interactive learning and innovation processes are not space-less or global, but on the contrary unfold in a way where geographical space plays an active role. Spatial proximity carries with it, among other things, the potential for intensified face-to-face interaction, short cognitive distance, common language, trustful relations between various actors, easy observations, and immediate comparisons (Malmberg & Maskell, 2002). In short, spatial proximity seems to enhance the processes of interactive learning and innovation; therefore, industrial systems should be assumed to have a distinctly localized component. Fourth and finally, an implication of the above is that there are reasons to believe that the knowledge structures of a given geographical territory are more important than other characteristics, such as general factor supply, production costs, etc., when it comes to determining where we should expect economic growth and prosperity in today's world economy.

University at the center of attention - The Triple Helix Model

In the innovation system and cluster frameworks technological change and innovation are the result of an evolutionary process. They are created through interaction between various actors from the academic, public and private sectors. To analyze these developments and provide policy guidance of their future development, models of relationship among the institutional spheres and their internal transformation have been developed. One of these is the "triple helix" mode of innovation where the analytical focus is on the triadic relations between industry, government and university within an innovation system (Etzkowitz, 2002).

Especially the universities have in the last few decades received a lot of attention in their role in creating new knowledge, which have been used in industrial applications. As mentioned above the knowledge structure of a geographical area is an imperative determinant in evaluating economic growth potential. In the center of these knowledge structures the universities have been placed. For example as expressed in the UN millennium program:

> Innovation makes a powerful case for development policies to focus on key sources of economic growth, particularly the use of scientific and technological knowledge and related institutional adjustments. It outlines core areas for policy action, including a focus on platform or generic technologies, defining infrastructure services as foundations for technology, placing universities at the center of local development (UN Millennium Project, Internet).

This development has been driven by the evidence of some US universities being successful in commercializing university research. A large reason to the achievement has been attributed to the Bayh Dole Act[105], enacted in 1980, encouraging commercial application of publicly sponsored research at universities (Thursby & Thursby, 2003). With this understanding the academic sphere has been allotted its own analytical position in the triple helix model. What is of interest in the framework is how knowledge is capitalized through the public, academic and private sector helices through three dimensions. First is internal transformation in each of the three helices, which could be universities assuming an economic development mission or companies forming strategic alliances. Second is how the helixes start to influence each other, for instance the government implementing policies to speed up technology transfer activities. Third is the creation of networks and organizations from the interaction among the three helices, formed for the purpose of establishing new ideas, visions and plans for high-tech development (Etzkowitz, 2002).

[105] In the Bayh Dole Act from 1980 universities are given the IP rights of discoveries and innovations originating from publicly sponsored research.

Summary

What the innovation system, cluster approaches have been stressing is the importance of interaction between various actors in the public and private sectors of the economy in the innovation process. As understood from the triple helix model innovation is increasingly likely to come from institutional spheres such as the university (where focus is on making ground breaking discoveries) and thus outside of individual companies. Furthermore innovations that originate in companies are also likely to be utilized in other contexts where the restrictions of current practices or commitment to existing technologies and products are less likely to be as dominating. When innovation moves outside of a single organization, relationships across boundaries become more important (Etzkowitz, 2002).

APPENDIX 2: Interviews

No	Respondent	Organisation & Position	Date
1	Ingemar Daniel	GE Healthcare: Product: Manager	2004-09-07 and other occasions
2	Lorentz Larsson	GE Healthcare: Sales Representative	2004-09-08 and other occasions
3	Annelie Sköld	GE Healthcare: Sales Representative	2004-09-08 and other occasions
4	Markus Johansson	GE Healthcare: Sales Representative	2004-09-10
5	Magnus Persson	Biovitrum: Researcher	2004-09-12
6	Shun Fai Sze	GE Healthcare: Sales representative	2004-10-28
7	Kam Hing So	GE Healthcare Hong Kong: Country Manager	2004-10-28
8	Michael Lai	GE Healthcare: Sales Representative	2004-11-04 and other occasions
9	Michael Chia	GE Healthcare: Country Manager Taiwan	2004-11-04 and other occasions
10	Chao Hsun Yang	Ching Kuo Institute: Professor	2004-12-03
11	Lillian Wei	GE Healthcare: Product Manager	2004-12-09 and other occasions
12	Kuo Chang Tang	ITRI: Director, International Program	2005-01-19
13	Michael Nystrom	ITRI: Analyst	2005-01-19 and other occasions
14	Joseph Z. Shyu	National Chiao Tung University: Professor	2005-01-19
15	Hsiao Cheng Yu	National Chiao Tung University: Professor	2005-03-15
16	Kuang Wen Liao	National Chiao Tung University: Professor	2005-03-15
17	Hsiao Yu Chen	Academia Sinica: Principal Investigator	2005-03-15
18	Irene Lin	DCB: Principal Investigator	2005-03-17 and other occasions
19	Min Chuan Huang	National Taiwan University: Professor	2005-03-22 and other occasions
20	Chiang Chih Lei	DCB: Project Manager, Biofronts project	2005-03-28 and other occasions
21	Shang Pwu Shia	Nankang Biotech Incubation Center: Director	2005-03-28 and other occasions
22	Jenny Chang	BPIPO: Manager	2005-03-29
23	Chen Chei Hsiang	BPIPO, MOEA: Director	2005-03-29 and other occasions
24	Jenny Chen	MOEA: Manager	2005-04-13 and other occasions
25	Geoff Yang	MOEA: Manager	2005-04-13
26	Carol Lin	PRIT Biotech Co Ltd: Sales Representative	2005-04-15
27	Tai Hsiao Shan	ATIT Innovation Incubation Center: Investigator	2005-04-15
28	Katie Huang	ATIT: Senior Research Fellow	2005-04-15 and other occasions
29	Nishimoto Fuminori	GE Healthcare: Senior Manager	2005-05-02
30	Mami Okudaira	GE Healthcare: Product Manager	2005-05-02
31	Atsushi Iimuro	GE Healthcare: Marketing Director	2005-05-02
32	George Yeh	Taiwan Liposome Company: General Manager	2005-05-05 and other occasions

33	Yun Long Tseng	Taiwan Liposome Company: Research Director	2005-05-05 and other occasions
34	Ching Chih Tsai	Taiwan Liposome Company: Researcher	2005-06-10
35	Annie Lu	Novartis: PR manager	2005-10-03
36	Herbert Wu	ABGenomics: Co-founder, Professor (NTU)	2005-10-13 and other occasions
37	Chester Ho	Boston Life Science Venture Corporation: Director	2005-10-15 and other occasions
38	Alex Lee	GE Healthcare: Sales Representative	2005-10-16
39	Christine Hsu	GE Healthcare: Sales Representative	2005-10-16
40	Andrew Lin	GE Healthcare: Sales Representative	2005-10-16
41	Keelung Hong	Taiwan Liposome Company: CEO and Founder	2005-10-17 and other occasions
42	Junko Yoshimoto	Novartis Pharma KK: PR Manager	2005-10-19
43	Stephan Mumenthaler	Novartis: Head Economic Affairs	2005-10-19
44	Koyo Matsuda	Novartis Pharma KK: HR Manager	2005-10-19
45	Masaki Nishino	Novartis Pharma KK: Brand Manager	2005-10-19
46	Yasumasa Kondo	Novartis Pharma KK: Department head External Affairs	2005-10-26
47	Toshiharu Kunihira	Novartis Pharma KK: External Affairs	2005-10-27
48	Takanori Kanazawa	Novartis Pharma KK: Principal Investigator,	2005-10-27
49	Yusuke Nagae	Novartis Pharma KK: Head Development Division	2005-10-27
50	Su Yeu	National Yang Ming University: Professor	2005-11-02
51	Wu Rong Tsun	National Yang Ming University: Professor	2005-11-02
52	Chang Rai Yuan	CDC Vaccine Center: Researcher	2006-01-18 and other occasions
53	Liu Ding Ping	CDC Vaccine Center: Director	2006-01-18
54	Rachel Yang	TLC: Researcher	2006-01-24
55	Mitsuaki Kusunoki	Toudai TLO: Licensing Associate	2006-04-07 and other occasions
56	Paul Liu	National Cheng Chi University: Professor	2006-07-10
57	Benjamin Jen	Quanta: Director of Venture Capital Section	2006-07-17
58	Anida Chen	PWCM (Venture Capital): Manager	2006-07-18
59	Yvonne Shih	PWCM: Manager	2006-07-18
60	Felix Hsieh	PWCM: Analyst	2006-07-20
61	Sabrina Lee	PWCM: Analyst	2006-07-20
62	Kenji Harada	JAFCO (Venture Capital): Analyst	2006-07-20
63	Yoji Tsukagoshi	Venture capitalist	2006-08-03
64	Pele Chong	National Health Research Institutes, Vaccine Center: Director	2006-12-27 and other occasions
65	Chen Hsin Wei	National Health Research Institutes: Principle Investigator	2006-12-27
66	Lee Min Shi	National Health Research Institutes: Senior Researcher	2006-12-27
67	Julie Sun	Biotechnology Industry Study Center, Taiwan Institute of Economic Research: Director	2006-12-29 and other occasions
68	Jack Chang	Industrial Economics and Knowledge Center, ITRI: Director	2006-12-30 and other occasions

69	Lee Chong Chou	Biotechnology Program, STAG: Director	2006-12-30 and other occasions
70	Evelyn Wu	BPIPO, MOEA: Manager	2007-01-03
71	Charity Lin	Quanta Venture Capital: Analyst	2007-07-10 and other occasions
72	John Wu	China Trust Venture Capital Division: Analyst	2007-07-11
73	Chi Ming Liang	Office of Public Affairs, Academia Sinica: Director	2007-07-16
74	Ida Wu	Academia Sinica: Patent Analyst	2007-07-16
75	Chen Mei Ching	Academia Sinica: Patent Analyst	2007-07-16

APPENDIX 3: Abbreviations

ASIC: Application Specification Integrated Circuit

ATIT: Animal Technology Institute Taiwan

BNHI: Bureau of National Health Insurance

BPA: Bureau of Pharmaceutical Affairs

BPIPO: Biotechnology and Pharmaceutical Industries Program Office

CDC: Centers for Disease Control

CDE: Center for Drug Evaluation

cGMP: Current Good Manufacturing Process

CMOS: Complementary Metal Oxide Semiconductor

DCB: Development Center for Biotechnology

DoIT: Department of Industrial Technology

ERSO: Electronics Research Service Organization

FDA: Food and Drug Administration (US)

ITRI: Industrial Technology Research Institute

MOEA: Ministry of Economic Affairs

NHRI: National Health Research Institutes

NSC: National Science Council

NTU: National Taiwan University

RCA: Radio Corporation of America

STAG: Science and Technology Advisory Group

TLC: Taiwan Liposome Company

TSIA: Taiwan Semiconductor Industry Association

TSMC: Taiwan Semiconductor Manufacturing Company

USFLL: University of San Francisco Liposome Laboratory

UMC: United Microelectronics

VLSI: Very Large Scale Integration

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