# Scrutinizing an economic development model – The Taiwanese semiconductor industry revisited

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### Abstract

To promote industrial development and economic growth is a vital issue for governments all over the world. The ideals guiding policymakers in their endeavours, strongly influenced by traditional economics and the innovation system approach, are that innovations based on new and advanced knowledge are central for industrial and economic development. As is exemplified through the quote below policymakers have no problem with finding inspiration from success cases such as Silicon Valley.

> The idea that so much could grow in so short time within such small geographical area sent planning bodies from Albuquerque to Zimbabwe scrambling to grow the next Silicon Valley on their own backyard. Sturgeon (2000: p.15)

But although the identified "generic" features have been copied, there are few examples of how ambitions to "artificially" create policy supported high-tech based business regions and industries have succeeded. One of the few successful examples of policy created high-tech industries often mentioned is the Taiwanese semiconductor industry. The story of the Taiwanese semiconductor industry is just as impressive as the one of Silicon Valley; in just a few decades an industry was developed from scratch. One of the most common explanations to the transformation addresses the governing role of the state in coordinating industrial development. Some of the major factors mentioned were for example the creation of public research institutes, the public provision of R&D, and the subsequent transfer of technologies to a downstream sector created by Taiwanese policy. This envisioned development scenario has been strongly supported in Taiwanese policy circles and forms a foundation of contemporary Taiwanese industrial development policy. However applied to biotechnology this economic development model has been widely criticized for not fulfilling it promises.

This paper challenges the so called "semiconductor development model" by investigating the emergence of the Taiwanese semiconductor industry from a resource interaction perspective. By comparing this picture with Taiwanese policy's interpretation it is argued that the development model is clearly over-simplified omitting several important factors in the development, for instance the importance of users as active participants in the development process.

**Keywords:** Industrial development, Resource interaction, Taiwan, Semiconductor industry

## *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 (2007: p5):

> 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).

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 development 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 centres. 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. At that time, 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 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[1] and consisted of nearly 400 companies[2]. At the end of 2005 the Taiwan

[1] Defined in terms of production value, surpassed only by the USA, Japan and Korea.

Semiconductor Industry Association (TSIA) estimated that 60 per cent of worldwide semiconductor foundry, package and testing revenue, 25 per cent of worldwide 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 development 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 developed 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).

The recipe's application on for example biotechnology in Taiwan has however been considered a failure. Although some policymakers claim that it is the inherent differences between semiconductors and biotechnology that lies behind the "unsuccessful" application of the model, this study argues that it is rather the interpretation of the emergence of the semiconductor industry which is over-simplified. Hence this paper will scrutinize the policy interpretation of the emergence of the semiconductor industry from a different perspective namely the resource interaction perspective and the aim is to:

- *To increase the understanding of the processes whereby new material and immaterial resources are developed, produced and taken into use within an industrial development process.*

## Methodology

For the investigation three different empirical settings will be considered, developing, producing and using. These are represented by resources structures related to existing material as well as immaterial resources in the business landscape. Each one of the resource structures which are associated with activities related to development, production and use (settings) 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 developments in these settings are often not primarily concerned with the economic returns the developed solution can potentially bring in, but on the novelty of the research. 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

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[2] 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).

individual company but a whole structure of related resources used by also other companies, organizations or individuals. 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; Ford et al., 2009).

The importance of considering anything new in relation to established (business) 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 (www.impgroup.org). 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[3].

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 which are considered to have great 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 established business structures. With this understanding the picture changes from, for example, the commonly used notions of push or pull[4].This dissertation also takes the analysis a step further compared with previous IMP studies which have mainly focused on development within established business relationships. In this study I investigate what happens when new solutions developed outside established business structures, i.e.,

[3] In his doctoral dissertation Andersson 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.

[4] 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."

the existing producer-user interfaces are introduced into the latter. The view is identified will also be related to the policy interpretation of what happened.

## Research design

The research methodology used in this paper is single case study, motivated by the ambition to investigate in depth the resource interfaces in different contexts (Yin, 1994). To collect and analyze data on the role of resource interfaces in the use of new technological solutions I have applied a “resource interaction” model developed in Håkansson and Waluszewski (2002). This model emerged in turn from the IMP[5] Industrial Network tradition, which assumes that due to resource heterogeneity, activity interdependency and incompleteness of actors, producers and users interact over time and become embedded in a network of connected exchange relationships (e.g. Axelsson and Easton, 1992; Ford et al, 2003; Håkansson and Snehota, 1995). The resource interaction model is based on the understanding that for any new technology to be utilized, interfaces has to be developed to other tangible and intangible resources (for applications see Baraldi and Waluszewski, 2005; Harrison & Waluszewski, 2008).

In mapping the interactions whereby resources are developed and used, the *interfaces* between resources are of central interest, that is, how resources affect each other technically, economically and socially (Håkansson & Waluszewski, 2002; Baraldi, 2003). By using a resource as a point of departure a larger structure of resources can be constructed. In the next section a more detailed overview of the analytical framework is given.

[5] The Industrial Marketing and Purchasing Group - see http://www.impgroup.org - for more details.

## Analytical framework

This dissertation concentrates on the resource dimension and more specifically on the development of resources in a business setting. The fundamental assumption employed by the IMP perspective concerning resources is that they are heterogeneous. The notion of heterogeneity[6] was first made by Penrose (1959) who suggested 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 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 analyse the interaction between heterogeneous resources?

First I will analyse the empirical material in terms of three empirical settings; developing, producing and using. These settings can all be a part of established 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 producer or user 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 development of interfaces in the settings and between them, I 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[7], 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 industries to emerge there needs to be three different factors, development, production and use of resources (Håkansson & Waluszewski, 2007). These activities make up three different settings in which value is created. Each activity and setting has its own characteristic and function. Nonetheless they need to work together and be able to benefit from each other in order for value creation in an industrial context. However, since the settings have varied driving forces they cannot be fully harmonized (Håkansson & Waluszewski, 2007; Ford et al., 2009) In this dissertation these settings are discussed in terms of resource structures related to developing, producing and using. 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 there follows a discussion of these structures.

**A developing structure**: Before a product or innovation can be produced or used it needs to be developed.[8] Traditionally within IMP, development, production and use have all been studied within established business structures, but even so it is difficult to create interfaces. However, an even greater challenge is when development occurs in a different structure than the established business setting. In this particular study, the developing structures, consisting of material and immaterial resources, are often represented, for example, by academia or research institutes. Given the nature of their activity, that is to say conducting scientific research and development, the ideas of use and production are often very vague, especially in the case of "radical" innovations (Håkansson & Waluszewski, 2002; Håkansson & Waluszewski, 2009).

[6] 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).

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

[8] 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.

**A (business) producing structure**: The producing structure refers to the material and immaterial resources available to produce a certain product etc. The typical producing company is highly reliant on suppliers[9], implying that the amount of existing investments is considerable. Thus the producing resource structures need to take into account the economic consequences of building in something new. The technical characteristics of the new have to balance with the economics of production. The input which is brought into the established structure needs to have some connectivity to the old (Gadde & Håkansson, 2001). Thus an important issue is whether the production of a new resource fits into the existing production structure. With the introduction of something new, resource interfaces are central for how new knowledge is being built in to a producing structure (Wedin, 2001). The interaction with users is also critical, as they are the ones deciding what will be purchased, i.e., the revenue comes from the users. This will have a large impact on the decisions made for production in the business setting (Håkansson & Waluszewski, 2007).

**A (business) using structure**: In the using structure, the innovation is confronted with the users' already established resources, material as well as immaterial. Thus use is not something which occurs "naturally", it depends to a large extent on what kind of sacrifices the users want to make to bring in new resources, whether a new machine or a drug. This decision is based on what effects, i.e., positive economic benefits, the innovation can create on the existing investments. Some issues that need to be considered are, for example: What costs are incurred with the innovation? Which legal obstacles are there, social or political etc.? (Håkansson & Waluszewski, 2009; Harrison & Waluszewski, 2008)

By investigating the particular characteristics of the different empirical settings, there might be 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. In order to identify resources and investigate the interactions that occur we need a search tool. In this dissertation, resource interaction will be analysed is through the *4R model* developed by Håkansson and Waluszewski (2002).

## The 4R Model and resource interaction

The 4R model was developed 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:** The first category of resources is physical artefacts. The features and uses of products are created in the interaction between users, producers and developers, thus they are part of both organizational units and relationships. Examples of products are cars, pharmaceutical drugs, and micro-chips.

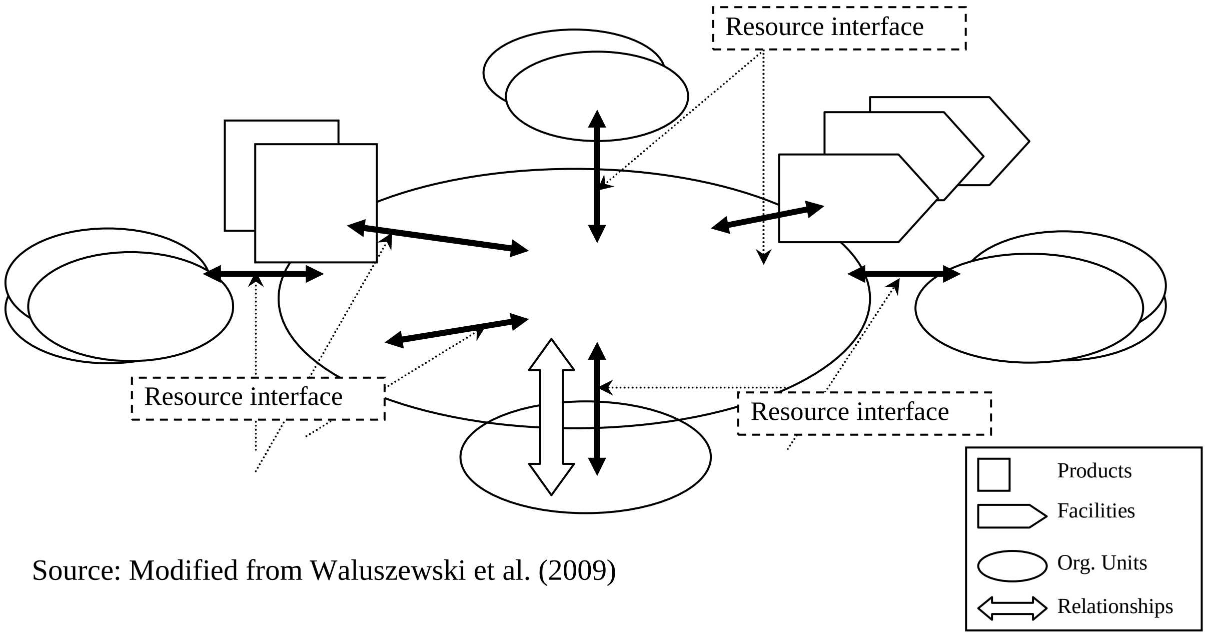
**(b) Production facilities:** Facilities are also physical and these are used in the production, modification or manufacturing of products. Examples of facilities are warehouses, laboratories, production plants, factories or equipment.

**(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.

[9] For example, of Volvo's total costs 70-80 per cent is derived from purchasing goods from suppliers (Gadde & Håkansson, 2001: p5).

**(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 1: An illustration of the 4R model and interfaces**




Source: Modified from Waluszewski et al. (2009)

As can be seen from Figure 1, both material (physical) and immaterial (social) resources are combined into a larger resource structure. 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.

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

The development 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. I also viewed the development of these settings from an interactive perspective. In this part I will describe how the development of a Taiwanese semiconductor industry has been interpreted by policy and become an influence to Taiwanese policy on how to create new science-based industries.

Just as Silicon Valley[10] 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

[10] "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).

> 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, 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[11] & 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 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 the table below, the role of the government is outlined in four different stages of the development of the semiconductor industry:

**Table 1: 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** | Foreign companies | ITRI and a pilot plant | Emergence of | Many firms, |

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

| | | | | |
|---|---|---|---|---|
| **structure** | (only involved in assembly and did not contribute to development) | | domestic companies in manufacturing and design | 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 this is discussed by Chang, Shih & Hsu (1994), it was the Taiwanese government that took the initiative, and 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 programme *Hsinchu Science Park* was established in 1979.[12] 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

[12] The Hsinchu Science Park is often referred to as a "public sector version" of Silicon Valley and is until today host to the majority of the Taiwanese semiconductor companies (Mathews 1997).

their revenues on R&D, and that a minimum percentage of workers must be scientists and engineers.

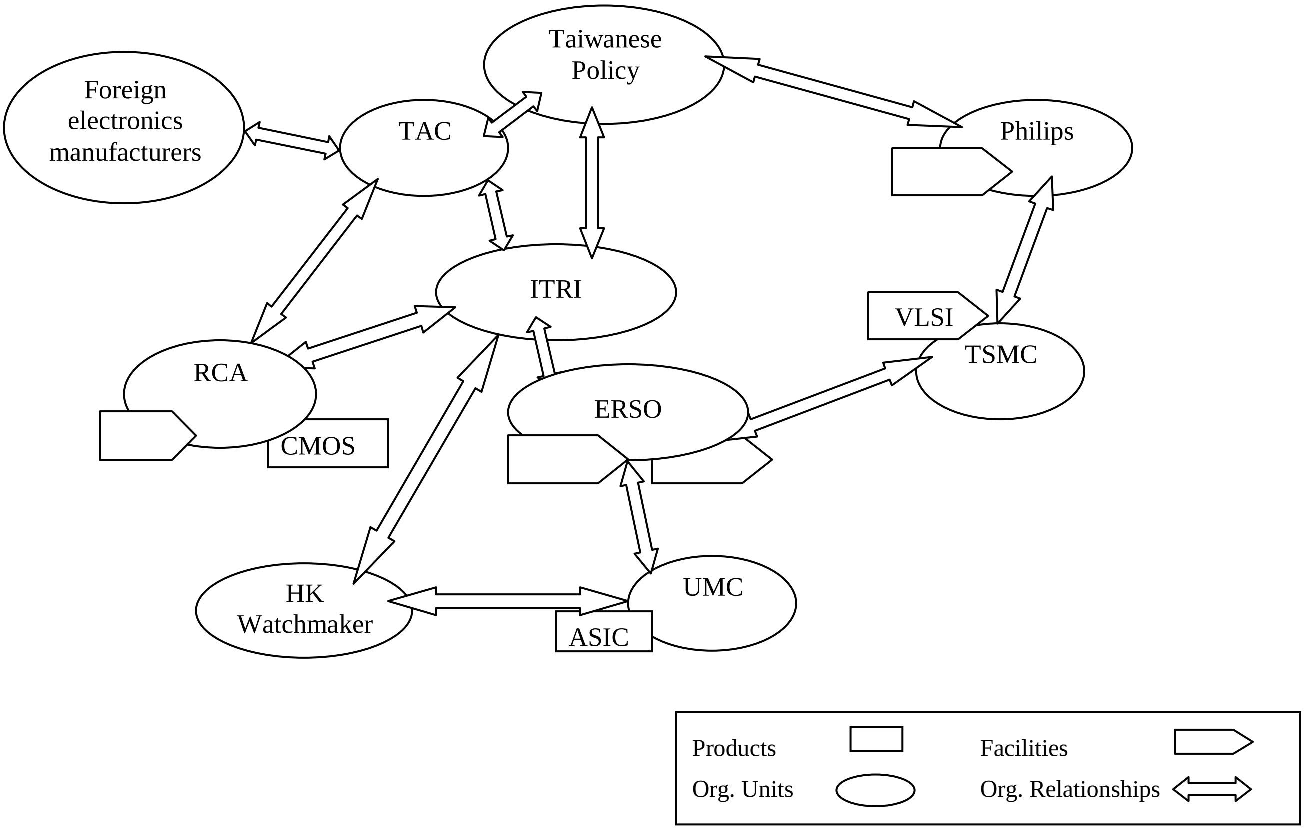
To sum up, the view which has been outlined is that government played a central role in the development of the semiconductor industry, all the way from providing and developing technology to transferring it to the industry (Hsu, 1993; Chang, Shih & Hsu, 1994). Before the government actively started to 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, etc were provided by the government to encourage private participation in the industry. (Liu, 1993)

In short the policy understanding can be summarized in two main points: 1) the semiconductor industry was instantly created at a specific place; 2) industrial development is an issue of linearly transferring of research results to the industry. These characteristics will be discussed more thoroughly later, but before doing so we will first take a closer look at the empirical material from a resource interaction perspective. This will give an empirically based understanding of how the industry emerged and bring forward a complementary picture of 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.

### *The interaction between resources in the development of the Taiwanese semiconductor industry*

In this section 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 empirical structures in developing, producing and using settings. Although there have been many interfaces worth studying, only a few with relevance for the research scope are discussed. In the figure below a network map of some of the important resources in the development are mapped out[13].

**Figure 2: Network map of key resources involved in the semiconductor case**




### The developing setting

Let us first consider the developing setting. In 1973 ITRI was commissioned by the Taiwanese government to develop semiconductor technology and create 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 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.

**Organizational interfaces**: A developing structure emerged in Taiwan with a clear aim of quickly speeding up Taiwan's entry into global semiconductor business. It was done through setting up 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 Chiao Tong University had established Taiwan's first semiconductor laboratory in the 1960. However universities played a significant role in training and educating

[13] In the figure the interfaces are not mapped out, instead the main interfaces between the resources are discussed in the subsequent text.

the personnel at ITRI. The capabilities and knowledge within ITRI was developed over an extended period of time. An important factor to the early development of the developing structure was established semiconductor knowledge sources. The empirical material illustrated how much of the knowledge of semiconductors stemmed from Taiwanese professionals working within established companies and research environments. Through these connections the door was opened to a rather special source of knowledge. Almost all 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 also these experienced semiconductor experts that 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 organisational interfaces to not only other developing structures but also to both established producing and using structures mainly in the US. It was through these interfaces which ITRI were able to both get access to technologies (in the beginning a mature one, but later also more advanced ones), and knowledge.

**Physical interfaces**: The developing structure was not only built up through the help of experienced people and organisational units outside of ITRI. In addition to the creation of such organisational 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. The directive from the government to develop semiconductor technologies to help start a local industry was not going to just come from nowhere. ITRI needed a 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. 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 tested out in producing and using structures, i.e. the technology had already established user and producer interfaces.

**Connection between organizational and physical 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 and testing technology and also training of 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 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, the semiconductor development could progress quite quickly. However as mentioned earlier this did not lead to any major developments business-wise. The explicit goal of the developing structure was not to primarily make any economic returns on any of 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. As it was demonstrated in chapter 4 both policymakers and the individuals 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. In the following two decades after the birth of ITRI the developing structure became incrementally more advanced. 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 par with world standards, a large reason 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 as the empirical material discussed 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 partly forming 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.

**Organizational 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 which a larger producer-user network could be distinctively noticed in the economic statistics. However over these decades an intricate network of interfaces to producers-user settings had emerged. In this period the developing structure had already had extensive interaction with established business structures, something which also were inherited by the producing structure as these were direct off-springs of the developing structure. Although what can be understood from the empirical material is that the organisational interfaces that were created were many times not consciously a part of an ambition to build up a semiconductor industry. For instance the relationships developed between foreign electronic companies and the Taiwanese government was 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 with Taiwanese companies, policy and the foreign companies were established, there was continuity in their interaction. But it was after many years of infrastructure build-up and commitment from the Taiwanese government which some of the foreign companies present in Taiwan eventually became to some extent interested in the Taiwanese semiconductor industry.

**Physical interfaces**: Until the 1980s the capabilities and technologies of the producing structure had already been built up through a large number of resource combinations with both developing and producer-user structures. As mentioned the mature CMOS technology from RCA was an advantage for the development 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 directly connect 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 already a year after the signing of the contract with RCA.

The most remarkable development in the creation of technological interfaces occurred in the case of TSMC. The company was created through spinning of 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 Philips. The development also brought advanced production technology to related interfaces. For example ITRI were able to upgrade its capabilities, facilities and technological levels. Furthermore a large number of supplier and sub-suppliers to the producing structure were able to benefit from this development.

**Connections between physical and organizational interfaces**: The known applications of the CMOS technology (with finished products) made it easy to identify existing users. Just 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 as well as its first customer. Thus the first Taiwanese semiconductor company became a producer of reliable but non-advanced semiconductors, catering mainly small Southeast 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 global semiconductor business. The birth of semiconductor foundry and Taiwan's flagship company TSMC was the result of the interaction between ITRI, Philips and the Taiwanese government. These organisational 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 got one of the largest electronics companies in the world as their customer from the start. This allowed TSMC to upgrade their manufacturing technology and skills in record time. By becoming a supplier to a large and advanced user not only served beneficial in upgrading the technology of TSMC but it also drew the attention of other large electronics companies such as Intel, Texas instruments to mention a few that later also became customers to TSMC.

## The using setting

Let us now continue with taking a closer look at the using setting and more specifically on 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?

**Organizational interfaces**: The connections the Taiwanese industry had with a using structure can be traced back to the multinational electronics companies that 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 established producer-user settings. However as was mentioned in chapter 4 Taiwanese policy did not believe that the foreign electronics companies played an important role in the emergence of the semiconductor industry at that time. What was believed was 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 which they were considered an important part by the Taiwanese government. But as the empirical case shows it is difficult to separate and neglect the role which the foreign companies played before the Taiwanese industry started to grow fast 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 where 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 in 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.

**Physical interfaces**: 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 after. Most of these advanced companies were fully vertically integrated concerning design, 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 semiconductors manufacturers neither did they produce anything of economic value for them.

It would have been unlikely that the foreign companies would 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 were not supported by any business users, there was simply no interest from the advanced foreign companies. Taiwan and UMC had little to offer these companies for that purpose even up to the 1980s. TSMC on the other hand received the support from an advanced user, Philips, which were offered an opportunity to create an external supplier. On another note about two decades after that ITRI started to engage in the CMOS technology it had emerged to become a dominant standard in integrated circuits. From a user perspective the features (for example low power consumption) was much more important than novelty and untried solutions. The CMOS technology later became a niche product which ITRI's spin-off UMC became one of the few 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.

**Connections between physical and organizational interfaces**: For the other end of the user spectrum i.e. the advanced semiconductor companies what they wanted was not another company that could develop advanced technologies. Instead a solution that was created was a Taiwanese company, TSMC becoming a supplier of advanced semiconductors based on users' specifications. It was not a result of ITRI creating a high tech production plant and then finding customers. This 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 of 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 importantly was the 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 other.

## Comments

What this case has shown is how use, production and development were happening simultaneously. Furthermore development happened in close relation to an already existing using and producing structure. The close relations of the various settings were beneficial for the emergence of the industry. 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 arises shows how 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 already established presence in Taiwan in the 1960s were important the Taiwanese semiconductor industry 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 users of Taiwanese semiconductors). Thus the foreign companies had an important role in establishing a developing and producing structures.

Another important of aspect of connecting to already established 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 policy 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 customer located in Taiwan with consumer electronics assembly plants such as Philips). In large the semiconductor case shows how development was achieved by relying on the existing network of resources, both locally and internationally; within and beyond organisational borders.

## An understanding of how industries emerge from a resource interaction perspective

In the previous section the interaction of resources in an industrial development process was discussed. The processes of how the industry was illustrated through three different settings and interfaces between them. From the discussion of the interaction between resources there are three main characteristics which can be derived. These are summarized below through the following lessons.

**Resource interaction/combination 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 creates 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 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 occur simultaneously. For example development of semiconductors happened without following a linear approach according to which the innovation process requires first R&D, then production and finally use, each one happening as separate stages. It is instead clear how use-production-development were happening simultaneously or development happened in close relation to already existing using and producing structures. The emergence of a semiconductor industry was a result of combinatory efforts stretching at least over three decades. Only the developing structure, with the assistance of established knowledge sources took over a decade to establish research and production capabilities sources. The producing structures were built up over an even longer period with close contact to users. These users had established presence in Taiwan already in the 1960s and although they were not active at the time resource synergies were created. With this example it is illustrated that emergence of an industry is a trial and error process where variety and time are important components. The processes are planned by the actors involved but not fully controlled by any actor.

**The new is always introduced in a context, i.e. building on something existing:** The emergence of the semiconductor industry is the result of the interaction between various resource structures extending beyond spatial, organisational and technological borders. As been touched upon above there are no single mechanisms triggering the emergence of an industry overnight. However an important factor to value creation is the ability of different actors to take advantage of what has already been created in other structures. Thus what is implied is that any 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 established structures. Connecting to existing structures can both be advantageous but also have disadvantages. For instance in the semiconductor case the interfaces to existing structures proved beneficial. 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 structures. The Taiwanese government were able to create interfaces and connect different established structures, in developing, producing and using levels was important. That will say the ability to through the help of others, and in relation to others, create space for Taiwanese organisations and companies in an international network related to development, production and use. 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 importance of a using structure:** As has been discussed there are three necessary stages to take into consideration for innovation to 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 at focus and which has been clear in this study is the need to understand how the using structure creates demand and shapes the features of what is developed or produced. As the empirical study illustrated users are not passive and there are indirect effects of the 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 the 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.

Hence, how new solutions 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 do not automatically find a 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 users. This suggests that the study of embeddedness new resources into using structures is of relevance. As have been exemplified when producers and users of products are closely related to each other it seems like it is more beneficial. How the new solution can be embedded in a using structure is critical for an innovation coming into being. In this respect how something new can be embedded into established business structures is very much a fit with the already existing.

## Conclusions

This paper has investigated the emergence of Taiwanese semiconductor industry and its associated development template. 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 the development of 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 $4^{th}$ 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 attempt has however been considered a failure by many commentators, quoting for example the modest revenues of Taiwanese biotechnology companies, lack of innovative capacity and use of new technologies in the industry as reasons behind the disappointment. Another main opinion is also that biotechnology is too different from semiconductors and to expect a similar development is not realistic.

This study do not get any deeper into these issues more than to acknowledge that the two technological fields are different and that income in the Taiwanese biotechnology industry has been modest compared to 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 evident from the complementary picture provided by the resource interaction perspective. The main point which I want to bring forward is that the Taiwanese industrial development model, modelled after the semiconductor industry is clearly oversimplified. I do not criticize the simplicity of it per se but it is rather the underlying assumptions which are at question. Especially, the ones reflected in the government interpretation of how the semiconductor industry emerged.

The main findings of this study are that the emergence of the semiconductor industry was not the makings of one single actor, nor was the industry created overnight. Instead what has been argued is the necessity to consider that: resource combinations take place over different places and times; new solutions are always built on something existing; using structures are important in creating demand.

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