The innovation policy priorities in industry evolution: the case of Taiwan's semiconductor industry

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Abstract: This paper explores the innovation policy priorities in industrial evolution. This issue has not been discussed in most of the literature. Taiwan has devoted considerable resources to the semiconductor industry. Resources have been aimed at promoting research and development-based industrial activity and economic growth. This paper chose the Taiwan semiconductor industry for a case study study on the innovation policy priorities in industry evolution. Many of the policy tools for innovation were found to be different in the four phases. An 'Environment side' policy was shown to be vital for the initial phase of industry evolution. Government involvement in the later phase of industry evolution is not necessary. However, to maintain domestic technology capacity, the government should focus its industrial development strategy onto innovation for the next generation of technological R&D. 'Environment side' policy should play a vital role once again. In the above shifting pattern, policy establishments were pulled by the industry needs for evolution.

Keywords: industry evolution; innovation policy; policy priorities; semiconductor industry.

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1 Introduction

Schumpeter Dynamics pointed to new technology as a future omnipotent panacea. To be able to continue 'business as usual', new technology is an indispensable element that could also contribute to the self-destruction of businesses (Krupp, 1995). Theoretically, innovation is the engine for national technological development. However, innovation has excessively high risks and the return is uncertain. Intervention by the government is essential (Shyu and Chiu, 2002).

Public policy, in turn, provides direction and coordination to the national system of innovation (Freeman and Soete, 1997; Galli and Teubal, 1997; Nelson, 1993). The public role has the following aspects: it provides infrastructure in fields like education, technology transfer, incubators, and so on. It should act as a large-scale buyer of innovative products and services in the public sector (e.g. energy, traffic systems, city renewal, defence, and healthcare). It promotes prestigious projects like high-energy, astrophysics, manned space flight, and so on (Krupp, 1995).

Innovation policy includes science and technology (S&T) and industry policy (Shyu and Chiu, 2002). There are significant differences among countries, according to the individual national policy style (Furtado, 1997). Innovation policy research has been discussed in several nations (e.g. Shyu and Chiu, 2002; Nelson, 1990; Tanaka and Hirasawa, 1996; Lee et al., 1996; Beise and Stahl, 1999; Mustar and Larédo, 2002). The other stream involves cross-national perspectives on innovation policy (e.g. Ergas, 1987; Etzkowitz and Brisolla, 1999). Many of the determinants are more different across nations than within a nation. Government policy, legal rules, capital market conditions, factor costs, and many other attributes make these differences important.

Limited resources, coupled with seemingly unlimited demand for development, means that policies must be made regarding the allocation of scarce resources. During past decades, governments sought more ways of transparently dealing with the problem of scarcity. The public was given a role in determining priorities (Tisdell, 1981). While the need for priority setting in the context of limited resources is not questioned, there are both theoretical and practical debates on the most appropriate ways to determine priorities. Quantitative methods, such as cost–effectiveness, cost–benefit, and disease analysis burden, differ in their methodologies. However, each uses what is considered relevant data (e.g. epidemiological or economic evidence) to determine priority (Reichenbach, 2002).

Industry life-cycle and shakeout theories provide the theoretical foundations for how an industry typically evolves from an early 'fluid' state into one that is highly specific and rigid (Gort and Klepper, 1982). It is well recognised that the magnitude and rapidity at which industry evolution can occur depends partly on the industry's technological opportunities. In this perspective, these opportunities are themselves usually a lagged function of breakthroughs in science and technology (Teece et al., 1990). However, industry evolution might depend on a wide range of factors besides technological development and opportunities. It also depends strongly on the interaction between education, knowledge diffusion, structural flexibility, innovation, and competition (Gjerding, 1997; Lundvall, 1999). For developing nations, to strengthen their global competitive advantages for industries and maintain stable economic growth for the nation, governments must develop effective innovation policies to insure sustained competitive advantage and continued economic growth. In addition to the common macroeconomic and microeconomic policies, direct government involvement in technological acquisitions and development is necessary. In this regard, there is an apparent need to explore the innovation policy priorities in each phase of industry evolution.

It is generally recognised that the public sector was a determinant in the development of Taiwan's semiconductor industry in creating leading innovative institutions and shaping cooperation and coordination between public research and development (R&D) centres and firms, resulting in a different policy demand for Taiwan. It is essential for policy makers to understand the innovation policy priorities for each phase of industry evolution. This paper chose the semiconductor industry in Taiwan as an empirical case, because it is an appropriate representative for this subject. The Taiwan semiconductor industry performance is excellent and mature. Based on Rothwell and Zegveld's (1981) framework for innovation policies, this paper proposes a model to explore innovation policy priorities using an empirical case in the evolution of Taiwan's semiconductor industry. To facilitate exploring the innovation policy priorities for Taiwan's semiconductor industry, published or archived data analysis (e.g. Liu, 1993; Mathews, 1997), questionnaire survey (e.g. Shyu et al., 2001), and in-depth interviews (e.g. Mathews, 1997) were used.

This paper is organised as follows. Section 2 summarises the innovation policies and industry evolution. Section 3 reviews Taiwan's semiconductor industry and how the government provided incentives to promote private sector investment in the semiconductor industry. Methodologies applicable to the proposed model will be described in Section 4. Section 5 explores the priorities for innovation policies in the evolution of Taiwan's semiconductor industry. The conclusion is documented in Section 6.

2 Innovation policies and industry evolution

2.1 Innovation policy

Innovation policy includes S&T and industry policy. Science policy is the most supply-side-oriented and the least direct of these policies. Technology policy is the most difficult to define because technological research varies significantly in the continuum from relatively mono-disciplinary scientific research to multidisplinary commercial innovation. S&T policy aims to enhance the basic and applied research capacities of nations; it is basically supply-side oriented. The industrial policy is generally perceived as an instrument to reinforce industry competitiveness. Industry policy formation is based upon demand-side considerations (Shyu and Chiu, 2002). However, innovation policy oriented toward appropriate new product ideas, production processes, and marketing concepts can produce, at minimum, temporary competitive advantages (Jacobs, 1998).

The search for appropriate policy tools is not easy. Macro measures are not effective; thus, proposals like a general R&D tax credit are pointless. Policies must be designed to influence particular economic sectors and activities. In this regard, the essential policy problem is to augment or redesign institutions rather than to achieve particular resource allocations (Nelson and Winter, 1997). A list of possible innovation policies given by Rothwell and Zegveld (1981) is summarised in Table 1. The various policies are organised into three categories:

- supply: provision of financial, human resource and technical assistance, including the establishment of S&T infrastructure
- environment: taxation, patent policies and regulations, such as measures that establish the legal and fiscal framework in which an industry operates
- demand: central and local government purchases and contracts, notably for innovative products, processes and services.

Through these three categories, this paper provides a model to analyse the innovation policy priorities in industry evolution.

Table 1 Classification of innovation policy tools

Category	*Policy tool*	*Descriptions*
Supply side	Public enterprise	Innovation by publicly owned industries, setting up of new industries, pioneering use of new techniques by public corporations, participation in private enterprise
	Scientific and technical development	Research laboratories, support for research associations, learned societies, professional associations, research grants
	Education	General education, universities, technical education, apprenticeship schemes, continuing, and further education, retraining
	Information	Information networks and centres, libraries, advisory and consultancy services, databases, liaison services
Environment side	Financial	Grant loans, subsidies, financial sharing arrangements, provision of equipment buildings or services, loan guarantees, export credits
	Taxation	Company, personal, indirect and payroll taxation, tax allowances
	Legal regulatory	Patents, environmental and health regulations, inspectorates, monopoly regulations
	Political	Planning, regional policies, honour or awards for innovation, encouragement of mergers of joint consortia, public consultation
Demand side	Procurement	Central or local government purchases and contracts, public corporations R&D contracts, prototype purchase
	Public services	Purchases, maintenance, supervision and innovation in health service, public building, construction, transport, telecommunications
	Commercial	Trade agreements, tariffs, currency regulations
	Overseas agent	Defence sales organisations

Source: Rothwell and Zegveld (1981).

2.2 Industry evolution

A historical perspective is basic to understanding both the existing and future economic conditions. Not surprisingly, biological metaphors have frequently been employed in this context. Thus terms resonant with biological connotations, such as 'life cycle' and 'evolution', have become familiar in the literature of economics (see Hodgson, 1993; Mokyr, 1996). The notion of an industry life cycle has been most influential and applied, in various ways, to industry evolution interpretation. This subject is reviewed in the following before considering two major weaknesses. The first weakness is a unidirectional, almost deterministic view of change that fails to acknowledge the possibility that unpredictable events can fundamentally alter the course of an industry's development. The second weakness is an implicit assumption that private sector companies are the sole agents of economic change. This assumption is difficult to sustain in a world of states and blocs where international boundaries represent discontinuities between different policy environments.

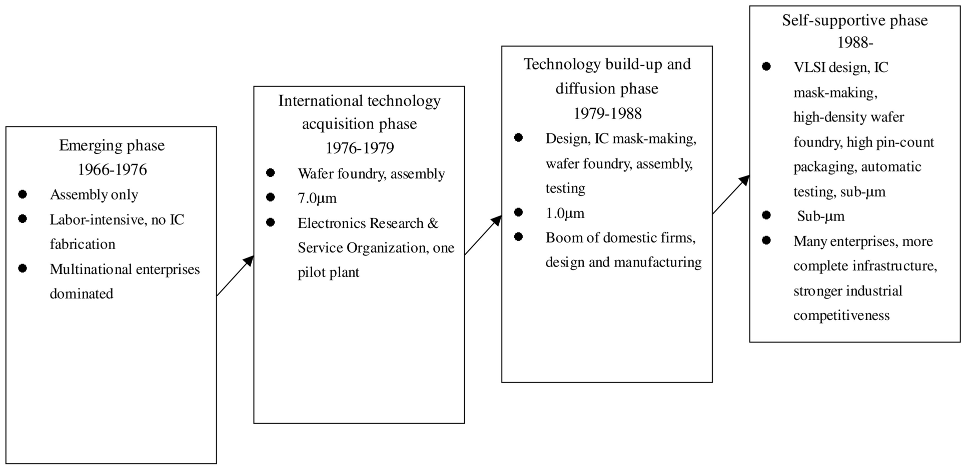
In various guises, this literature shows us that, in the early phases of an industry's life cycle, demand is fragmented across a variety of individual product variants that are produced primarily by young firms (Abernathy and Utterback, 1978; Clark, 1985; Jovanovic and MacDonald, 1994; Klepper, 1996, 1997). In this phase, there is no extraordinary comparative advantage to incumbency. Rather, there is a considerable amount of entry and exit into the industry and market uncertainty is high. Young firms are attracted by the ease of competing on novel product variants. This is what Geroski (1991) refers to as technological opportunities. In the later phases, dominant product designs become established and firms that do not adhere to these tend to go bankrupt or drop out into small niche markets. Learning from incumbent firms becomes incremental and cumulative with increasing returns on economic scale, raising barriers to entry. One result is an industry 'shakeout' leading to increased market concentration and lower uncertainty (Klepper, 1997). Depending on the prime theoretical orientation, industry shakeout is explained as the result of either decreased entry or increased exit.

Presented here are some findings from the literature review. The determinants and conditions in each phase of industry evolution are different. The priorities for innovation policy did exist. To strengthen the competitive advantages for industries and maintain the economic growth for the nation, direct (or indirect) government involvement in industry evolution is necessary. Moreover, no case involving Asian developing countries has been reported in the literature. This paper proposes a model to explore the innovation policy priorities in each phase of industry evolution using Taiwan's semiconductor industry as the case study.

3 Taiwan's semiconductor industry: an overview

Over past decades, Taiwan's economy has transformed from traditional industry into a high-technology industry. Although recessions have intervened, hundreds of billion of dollars were invested into the development of high-tech products, such as computers, multimedia, peripherals networks, and so on. Above all, with the boom in semiconductor manufacturing, Taiwan has grown into one of the largest manufacturers in the global market. The structural evolution of the semiconductor industry in Taiwan can be divided into four phases (see Figure 1) (Industrial Economics Research Center, 1987). There are several competent actors that supported Taiwan's semiconductor industry: the government, Industrial Technology Research Institute (ITRI), National Chaio Tung University (NCTU), National Tsing Hua University (NTHU), etc.

Figure 1 The structural evolution of the semiconductor industry in Taiwan



Source: Industrial Economics Research Center (1987)

The foremost role played by the Taiwan government in developing its semiconductor industry was to acquire technology from abroad and perform in-house pioneer research through a series of national research projects. A series of government funded Electronics Industry Development Projects were executed by the Electronic Research & Service Organisation (ERSO). The government concentrated on technological supplies and stimulated demand by helping firms across the industry spectrum speed up commercialisation of these technologies to meet specific market segments. ITRI is a national-level, government-sponsored non-profit institute for applied research in Taiwan. In selecting various means for transferring firm technologies, ITRI took into account the status of its technologies and the requirements and the existing technological capacities of the private sector. ITRI also spun off an entire semiconductor manufacturing operation to create several new firms, such as: the United Microelectronics Corp (UMC), and the Taiwan Semiconductor Manufacturing Co (TSMC). The government established the Hsinchu Science-based Industrial Park (HSIP) in 1980, to engage in building a brand new high-tech industry and upgrade current industrial technologies. HSIP is entirely government oriented. For instance; it is developed on public land with infrastructure facilities; efficiently supported one stop service; automated customs services, on-job training; domestic, and international network; investment incentives and benefits[1] etc. NCTU and NTHU are both advanced academic institutes in Taiwan, especially in electronics and information. They furnish this industry with talent enforcement activities, high-quality human resources and research and development support. Through these efforts, Taiwan's overall semiconductor production was valued at $17.4 billion in 2002. In 2001, there were more than 100 design firms in Taiwan. There are 20 firms producing wafers, over 40 firms involved in packaging and some 30 firms devoted to testing. The clustering phenomenon has occurred at HSIP.

4 Remarks on methodologies

Based on Rothwell and Zegveld's (1981) framework for innovation policies, this paper proposes a model for innovation policy priorities in the evolution of Taiwan's semiconductor industry (see Table 1). This framework is helpful to illustrate and explain the innovation policy priorities in industry evolution. With this framework important priorities can be observed and evaluated.

To facilitate exploring innovation policy priorities using an empirical case in the evolution of Taiwan's semiconductor industry, several methodologies will be introduced. Data analysis of the published or archived data is widely utilised in the literature as an objective method for corroborating proposed models and hypotheses (e.g. Liu, 1993; Mathews, 1997). The questionnaire survey is a multi-purpose approach capable of measuring either substantial or intangible indicators (e.g. Shyu et al., 2001). The in-depth interview is a judgment-based approach that can help researchers know the holistic system and the insider's operations, which are important for identifying critical drivers and interrelationships (e.g. Mathews, 1997).

5 Exploring the innovation policy priorities in the evolution of Taiwan's semiconductor industry

5.1 Sample and questionnaire

A questionnaire survey study was selected to provide information about the 12 tools used in the three types of policies (see Table 1) in Rothwell and Zegveld's (1981) framework. This information was used to explain the innovation policy priorities in the evolution of Taiwan's semiconductor industry. Stakeholders in this industry were asked to describe their perceptions of the 12 tools in three types of policies and how they impact on Taiwan's semiconductor industry using a 5-level scale (1 = significant negative effect, 2 = negative effect, 3 = no effect, 4 = positive effect, 5 = significant positive effect). Of 200 questionnaires sent out, 81 valid returns were received, a 40.5% valid return rate. In this survey, the majority of the respondents were managers at foreign-owned firms, locally owned firms, R&D institutions, academic institutions, and local government officials in Taiwan. Of 81 valid questionnaires, 46 were from firms, 21 from R&D institutions, eight from academic institutions, and six from government officials. The descriptive statistics are shown in Table 2.

Table 2 Descriptive statistics for replies

Category	*Policy tool*	*Phase*			
		1	*2*	*3*	*4*
Supply side[a]		3.657 (0.972)[b]	3.241 (0.976)	3.500 (0.902)	3.194 (0.808)
	Public enterprise	2.691 (0.768)	2.568 (0.907)	2.679 (0.849)	2.766 (0.763)
	Scientific and technical development	3.975 (0.632)	2.519 (0.823)	3.864 (0.770)	3.370 (0.679)
	Education	4.309 (0.861)	4.222 (0.880)	3.802 (0.660)	3.617 (0.663)
	Information	3.654 (0.777)	3.580 (0.739)	3.728 (0.689)	3.025 (0.851)
Environment side		4.071 (0.702)	3.707 (0.864)	3.444 (0.904)	3.383 (0.764)
	Financial	4.383 (0.624)	3.963 (0.697)	4.222 (0.570)	3.531 (0.709)
	Taxation	4.099 (0.644)	3.963 (0.926)	3.309 (0.903)	3.358 (0.841)
	Legal regulatory	3.926 (0.721)	3.260 (0.833)	3.333 (0.822)	3.222 (0.775)
	Political	3.877 (0.714)	3.963 (0.798)	2.914 (0.745)	3.420 (0.705)
Demand side		2.873 (0.991)	2.991 (0.927)	2.812 (0.979)	2.380 (0.822)
	Procurement	2.321 (0.834)	2.518 (0.792)	2.331 (0.812)	2.346 (0.727)
	Public services	3.815 (0.937)	3.901 (0.889)	3.383 (0.874)	2.370 (0.843)
	Commercial	3.037 (0.954)	3.099 (0.846)	3.062 (0.827)	2.802 (0.797)
	Overseas agent	2.321 (0.819)	2.506 (0.882)	2.506 (0.882)	2.000 (0.725)

Notes: [a] In each questionnaire, the grades of the policy tools in one category are averaged into the category's grade.
[b] The number in the bracket is the standard deviation

5.2 Empirical results

After the questionnaire collection was completed in April 2003, this paper used a one-way ANOVA (parametric method) and the Kruskal–Wallis (K–W) test (nonparametric method) to examine the four phases exhibited by the 12 policy tools. The results are shown in Table 3. Using a one-way ANOVA and the K–W test, the means and medians[2] were significantly different for nine policy tools for the four phases at the 0.05 significance level.

Table 3 ANOVA and Kruskal–Wallis test results for 12 policies for the four phases

	Significance levels of ANOVA[b]	*Significance levels of K–W test*[b]
A. Supply side[a]	0.000	0.000
A.1. Public enterprise	0.499	0.443
A.2. Scientific and technical development	0.000	0.000
A.3. Education	0.000	0.000
A.4. Information	0.000	0.000
B. Environment side	0.000	0.000
B.1. Financial	0.000	0.000
B.2. Taxation	0.000	0.000
B.3. Legal regulatory	0.000	0.000
B.4. Political	0.000	0.000
C. Demand side	0.000	0.000
C.1. Procurement	0.327	0.545
C.2. Public services	0.000	0.000
C.3. Commercial	0.267	0.136
C.4. Overseas agent	0.000	0.000

Notes: [a] In each questionnaire, the grades of the policy tools in one category are averaged into the category's grade.
[b] The difference is significant at the 0.05 level

Pairwise comparisons were used to determine the priority for the four phases on the 12 policy tools (see Table 4). It was indicated that phases 1 and 3 were significantly superior to phases 4 and 2 for 'Scientific and technological development'. Phases 1 and 2 were significantly superior to phases 3 and 4 for 'Education'. The priority for the four phases for 'Financial' was ranked phase 1, phase 3, phase 2, and phase 4. However, phases 1, 3 and phases 2, 3 were not significantly different. Both 'Taxation' and 'Legal regulatory' might be given precedence in phase 1 over the other phases. The priority for the four phases for 'Political' was ranked phase 2, phase 1, phase 4, and phase 3. However, phases 2 and 1 were not significantly different. The priority for the four phases for 'Public services' were ranked phase 2, phase 1, phase 3, and phase 4. However, phases 2 and 1 were not significantly different.

Table 4 Results of pairwise test for four industrial clusters

	i-variable	*j-variable*[a]	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
A.1. Public enterprise	1	2	0.124	0.741	
		3	0.001	0.924	
		4	−0.001	0.924	
	2	1	−0.124	0.741	
		3	−0.111	0.722	
		4	−0.198	0.769	
	3	1	−0.001	0.924	
		2	0.111	0.722	
		4	−0.001	0.924	
	4	1	0.001	0.924	
		2	0.198	0.769	
		3	0.001	0.924	
A.2. Scientific and technical development	1	2	1.457	0.741	(1, 2)
		3	0.111	0.722	
		4	0.605	0.000	(1, 4)
	2	1	−1.457	0.000	(1, 2)
		3	−1.346	0.000	(3, 2)
		4	−0.852	0.000	(4, 2)
	3	1	−0.111	0.722	
		2	1.346	0.000	(3, 2)
		4	0.494	0.000	(3, 4)
	4	1	−0.605	0.000	(1, 4)
		2	0.852	0.000	(4, 2)
		3	−0.494	0.000	(3, 4)
A.3. Education	1	2	0.001	0.924	
		3	0.506	0.000	(1, 3)
		4	0.691	0.000	(1, 4)
	2	1	−0.001	0.924	
		3	0.420	0.004	(2, 3)
		4	0.605	0.000	(2, 4)
	3	1	−0.506	0.000	(1, 3)
		2	−0.420	0.004	(2, 3)
		4	0.185	0.770	
	4	1	−0.691	0.000	(1, 4)
		2	−0.605	0.000	(2, 4)
		3	−0.185	0.770	

Table 4 Results of pairwise test for four industrial clusters (continued)

	i-variable	*j-variable*[a]	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
A.4. Information	1	2	0.000	0.999	
		3	0.000	0.999	(1, 4)
		4	0.630	0.000	
	2	1	0.000	0.999	
		3	0.000	0.999	
		4	0.630	0.000	(2, 4)
	3	1	0.000	0.999	
		2	0.000	0.999	
		4	0.630	0.000	(3, 4)
	4	1	−0.630	0.000	(1, 4)
		2	−0.630	0.000	(2, 4)
		3	−0.630	0.000	(3, 4)
B.1. Financial	1	2	0.420	0.000	(1, 2)
		3	0.161	0.711	
		4	0.852	0.000	(1, 4)
	2	1	−0.420	0.000	(1, 2)
		3	−0.259	0.072	
		4	0.432	0.000	(2, 4)
	3	1	−0.161	0.711	
		2	0.259	0.072	
		4	0.691	0.000	(3, 4)
	4	1	−0.852	0.000	(1, 4)
		2	−0.432	0.000	(2, 4)
		3	−0.691	0.000	(3, 4)
B.2. Taxation	1	2	0.457	0.003	(1, 2)
		3	0.790	0.000	(1, 3)
		4	0.741	0.000	(1, 4)
	2	1	−0.457	0.003	(1, 2)
		3	0.333	0.070	
		4	0.284	0.189	
	3	1	−0.790	0.000	(1, 3)
		2	−0.333	0.070	
		4	−0.001	0.924	
	4	1	−0.741	0.000	(1, 4)
		2	−0.284	0.189	
		3	0.001	0.924	

Table 4 Results of pairwise test for four industrial clusters (continued)

	i-variable	*j-variable*[a]	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
B.3. Legal regulatory	1	2	0.667	0.000	(1, 2)
		3	0.593	0.000	(1, 3)
		4	0.704	0.000	(1, 4)
	2	1	−0.667	0.000	(1, 2)
		3	−0.001	0.924	
		4	0.001	0.924	
	3	1	−0.593	0.000	(1, 3)
		2	0.001	0.924	
		4	0.111	0.722	
	4	1	−0.704	0.000	(1, 4)
		2	−0.001	0.924	
		3	−0.111	0.722	
B.4. Political	1	2	−0.001	0.924	
		3	0.963	0.000	(1, 3)
		4	0.457	0.001	(1, 4)
	2	1	0.001	0.924	
		3	1.050	0.000	(2, 3)
		4	0.543	0.000	(2, 4)
	3	1	−0.963	0.000	(1, 3)
		2	−1.050	0.000	(2, 3)
		4	−0.506	0.000	(4, 3)
	4	1	−0.457	0.001	(1, 4)
		2	−0.543	0.000	(2, 4)
		3	0.506	0.000	(4, 3)
C.1. Procurement	1	2	−0.198	0.697	
		3	0.000	0.999	
		4	−0.001	0.924	
	2	1	0.198	0.697	
		3	0.198	0.697	
		4	0.173	0.709	
	3	1	0.000	0.999	
		2	−0.198	0.697	
		4	−0.001	0.924	
	4	1	0.001	0.924	
		2	−0.173	0.709	
		3	0.001	0.924	

Table 4 Results of pairwise test for four industrial clusters (continued)

	i-variable	*j-variable*[a]	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
C.2. Public services	1	2	−0.001	0.924	
		3	0.432	0.013	(1, 3)
		4	1.444	0.000	(1, 4)
	2	1	0.001	0.924	
		3	0.519	0.001	(2, 3)
		4	1.531	0.000	(2, 4)
	3	1	−0.432	0.013	(1, 3)
		2	−0.519	0.001	(2, 3)
		4	1.012	0.000	(3, 4)
	4	1	−1.444	0.000	(1, 4)
		2	−1.531	0.000	(1, 2)
		3	−1.012	0.000	(1, 3)
C.3. Commercial	1	2	0.000	0.999	
		3	0.000	0.999	
		4	0.235	0.629	
	2	1	0.000	0.999	
		3	0.000	0.999	
		4	0.235	0.629	
	3	1	0.000	0.999	
		2	0.000	0.999	
		4	0.235	0.629	
	4	1	−0.235	0.629	
		2	−0.235	0.629	
		3	−0.235	0.629	
C.4. Overseas agent	1	2	−0.185	0.938	
		3	−0.185	0.938	
		4	0.321	0.086	
	2	1	0.185	0.938	
		3	0.000	0.999	
		4	0.506	0.001	(2, 4)
	3	1	0.185	0.938	
		2	0.000	0.999	
		4	0.506	0.001	(3, 4)
	4	1	−0.321	0.086	
		2	−0.506	0.001	(2, 4)
		3	−0.506	0.001	(3, 4)

Notes: [a] 1: Phase 1; 2: Phase 2; 3: Phase 3; 4: Phase 4. [b] The mean difference is significant at the 0.05 level. [c] (1, 2) means that Phase 1 has significantly higher grade than Phase 2 at a level of significance of 0.05.

The Tukey multiple comparisons test was applied to produce a ranking to indicate the sequence for the three categories for the four phases, respectively (see Tables 5–8). The priority for the three category effects on phases 1, 2, and 4 were ranked as 'Environment side', 'Supply side', and 'Demand side'. The priority for the three category effects on phase 3 were ranked as 'Supply side', 'Environment side', and 'Demand side'. However, 'Supply side' and 'Environment side' were not significantly different.

Table 5 Results of Tukey test for Phase 1 in three categories

i-variable	*j-variable*	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
A[a]	B	−0.414	0.000	(B, A)
	C	0.784	0.000	(A, C)
B	A	0.414	0.000	(B, A)
	C	1.198	0.000	(B, C)
C	A	−0.784	0.000	(A, C)
	B	−1.198	0.000	(B, C)

Notes: [a] A: Supply side; B: Environment side; C: Demand side
[b] The difference is significant at the 0.05 level
[c] (A, B) means that Supply side has significantly higher grade than Environment side at a level of significance of 0.05

Table 6 Results of Tukey test for Phase 2 in three categories

i-variable	*j-variable*	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
A[a]	B	−0.414	0.000	(B, A)
	C	0.216	0.019	(A, C)
B	A	0.485	0.000	(B, A)
	C	0.701	0.000	(B, C)
C	A	−0.216	0.019	(A, C)
	B	−0.701	0.000	(B, C)

Notes: [a] A: Supply side; B: Environment side; C: Demand side
[b] The difference is significant at the 0.05 level
[c] (A, B) means that Supply side has significantly higher grade than Environment side at a level of significance of 0.05

Table 7 Results of Tukey test for Phase 3 in three categories

i-variable	*j-variable*	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
A[a]	B	0.001	0.617	
	C	0.701	0.000	(A, C)
B	A	−0.001	0.617	
	C	0.627	0.000	(B, C)
C	A	−0.701	0.000	(A, C)
	B	−0.627	0.000	(B, C)

Notes: [a] A: Supply side; B: Environment side; C: Demand side
[b] The difference is significant at the 0.05 level
[c] (A, B) means that Supply side has significantly higher grade than Environment side at a level of significance of 0.05

Table 8 Results of Tukey test for Phase 4 in three categories

i-variable	*j-variable*	*Mean difference (i–j)*	*Significance levels of ANOVA*[b]	*Multiple comparisons*[c]
A[a]	B	−0.188	0.012	(B, A)
	C	0.815	0.000	(A, C)
B	A	0.188	0.012	(B, A)
	C	1.003	0.000	(B, C)
C	A	−0.815	0.000	(A, C)
	B	−1.003	0.000	(B, C)

Notes: [a] A: Supply side; B: Environment side; C: Demand side
[b] The difference is significant at the 0.05 level
[c] (A, B) means that Supply side has significantly higher grade than Environment side at a level of significance of 0.05

5.3 Discussions

Through a series of analyses, the innovation policy priorities in the evolution of Taiwan's semiconductor industry could be discussed using the four phases.

5.3.1 Emerging phase

An 'Environment side' policy is vital for the emerging industry evolution phase. The government also focused on 'Scientific and technical development' and 'Education'. Taiwan's semiconductor industry began in 1966 when General Instrument Microelectronics established a semiconductor packaging business in Taiwan. Later, multinational corporations, such as Philips, Texas Instruments and RCA, started packaging operations. Fewer domestic firms entered this field. All were labour intensive. In this phase, Taiwan had only semiconductor assembly technology capability. This was in accordance with cost-driven and export-oriented goals. To strengthen the domestic technological capacity, NCTU opened a semiconductor laboratory to foster advanced technology development and high-quality human resources in this field. An 'Environment side' policy is vital for the initial industry evolution phase. There is no extraordinary comparative advantage to incumbency. Rather, there is a considerable amount of entry and exit into the industry and market uncertainty is high. To attract more domestic participation in this industry the government initiated several policies (e.g. export credits, subsidies, and tax allowances) for it.

5.3.2 International technology acquisition phase

The priority for the three category effects on this phase were ranked as 'Environment side', 'Supply side', and 'Demand side'. 'Political', 'Public service', and 'Education' were executed seriously in this phase. The integrated circuit (IC) was introduced, in the late 1950s, by Texas Instruments. Their small size, low power consumption, rapid operating speed and reliability led to dramatic changes in the market. To take advantage of this transition, the Taiwan government opted to develop IC design and manufacturing technology to breed the related industries. However, the fast development of IC technology in leading countries led to a technology gap that made it difficult for Taiwan to independently develop commercialised IC technology. First, the private sector in Taiwan was too weak to afford the large, risky investment in R&D. Second, the private firms, basically cost-driven, were unwilling to invest in long-term R&D. They preferred to invest in areas with immediate returns regardless of whether the area was technology or labour intensive. Finally, acquiring technology from abroad and in-house pioneer research required hundreds of professionals, experienced engineers and scientists with intensive training. International technology acquisition strategies were therefore initiated to reinforce domestic R&D competence. ITRI was charged with acquiring generic technology and disseminating it to domestic firms. NCTU and NTHU also furnished this industry with talent enforcement activities, high-quality human resources and R&D support.

The government decided to establish an industrial park entirely devoted to high-tech industries, the Hsinchu Science-based Industrial Park (HSIP). HSIP was given infrastructure, back-up services and the intellectual climate for R&D. HSIP was the first high-tech industry development centre in Taiwan.

5.3.3 Technology build-up and diffusion phase

A 'Supply side' policy is vital for this phase. During this phase, ITRI's technology advanced from 7.0 to 3.5 μm. Photo mask production equipment set-up was completed in 1981. After this, ITRI began to supply masks to domestic IC firms and to its own pilot plant. This greatly reduced the time needed to introduce new products. At the same time, ITRI continued to develop photolithography to complement its high-density process. A Very Large Scale Integration (VLSI) Technology Development Project also took place between 1983 and 1988. The IC pilot plant was upgraded into a VLSI model plant. In this phase, the authority adopted technology diffusion strategies to develop a domestic semiconductor industry. In 1980, ITRI spun off an entire IC manufacturing operation to establish a new firm, UMC. This was the first private IC manufacturer in Taiwan. In 1987, TSMC, with capital from the government, private investors and Philips Inc., was established to provide design houses with IC foundry services. The establishment of TSMC allowed huge investments in manufacturing facilities. This policy stimulated rapid growth in the number of independent design firms in Taiwan. In this phase, ITRI also sent personnel to private firms as consultants, transferred entire departments to private companies, spun off research groups to establish new firms and implicitly encouraged personnel shifts.

This was complemented by the innovative capacity of firms to absorb and adapt these technologies and apply them in a productive way with significantly lower costs. The government concentrated on 'Supply' of technologies and stimulated 'Demand' by helping firms across the industry spectrum to speed up the commercialisation of these technologies to meet specific market segments (Branscomb, 1992).

5.3.4 Self-supportive phase

The priority for the three category effects on this phase were ranked 'Environment side', 'Supply side', and 'Demand side'. However, the innovation policy priorities were not significant. This exhibited that government involvement in the later phase of industry evolution is not necessary. This leads to increased market concentration and lower uncertainty.

However, with the present severe competition in the global semiconductor industry, product life cycles have been severely shortened, profit margins are extremely low and huge investments are required in R&D and advanced production facilities. Taiwan must actively nurture the technological and innovative capabilities of its engineers and skilled professionals. To keep strengthening the national competitive advantages in the global market, the government might maintain traditional technology acquisition and pioneer research and coordinate cooperative research and strategic alliances. Strenuous efforts should be made to elevate domestic technology capacity and to encourage cross-licensing. Consequently, the government should focus its industrial development strategy onto innovation for the next generation of technological R&D. This is the reason that 'Environment side' policy plays a vital role once again.

6 Conclusions

In this paper we chose Taiwan's semiconductor industry for an empirical study to explore the innovation policy priorities in each phase of industry evolution. This paper proposed a model for analysing this theme. An analysis series was used to facilitate exploring innovation policy priorities in industry evolution. Related improvement recommendations were made for the authorities in Taiwan.

There were many coincidences between the findings by this paper and the actual situation. The innovation policy priorities in each phase of industry evolution were confirmed. The determinants and conditions in each phase of industry evolution make the differences important. This study exhibited that 'Environment side' policy is vital for the initial phase of industry evolution. A considerable amount of entry and exit occurs into the industry and market uncertainty is high. Government involvement in the later phase of industry evolution is not necessary. This phase has increased market concentration and lowered uncertainty. However, the government might maintain domestic technology capacity; the government should focus its industrial development strategy onto innovation for the next generation of technological R&D. 'Environment side' policy should play a vital role once again. This case study contributes to the literature on the innovation policy priorities in industry evolution by providing a practical case from Asian developing countries, previously neglected in the literature.

Based on these findings, policies might be made regarding the allocation of scarce resources. From the above pattern shifting, policy establishments were pulled by the needs for industry evolution. Moreover, a lesson is provided for those countries that want to speed up the pace of industrialisation and shorten the lag behind industry leaders.

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Notes

1 Investment incentives and benefits are: tax incentives, protection of investors' rights, government's participation in investment, capitalization of technical expertise, capital raising, low-interest loans and R&D encouragement.

2 The K–W test is a nonparametric test for the null hypothesis that k samples from possibly different populations actually originate from similar populations, at least as far as their central tendencies, or medians, are concerned. The test assumes that the variables under consideration have underlying continuous distributions.