China's High-tech Industry in the International Division of Labor and Its Industrial Upgrading Strategies: A Case Study of the IC Industry

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ABSTRACT: The value chain of Integrated Circuit (IC) industry is composed of three segments including IC design, IC manufacturing, and packaging and testing. First, this paper analyzes the position of China's IC industry on international division of labor by exploring the industry scale, technology level and value added of three segments of China's IC industry and comparing those with their counterparts of the international IC industry. Secondly, based on production factors, technological features and investment scales of the three segments, the paper explains how the international IC industry is gradually migrating into China. The role of internal factors that have led to such transfer is also explored. Finally, the upgrading strategies and technology sources of those segments are also presented. The paper concludes that China's high-tech industries are located at the low end of the international value-train and are moving towards the intermediate and high ends. Policy suggestions are also included on how to enhance the competitiveness and indigenous innovation capacities of the industry.

I. Introduction

With the accelerated development of economic globalization since the 1990s, the high-tech industry has also evolved from an industry concentrated in a few developed countries into a global production network with clear international division of labor for different countries. Especially in recent years, the migration of the high-tech industry into China, represented by the information industry, the aircraft manufacturing industry and the integrated circuit industry, has changed China into a manufacturing workshop of high-tech products. As a result, China has seen a continuous rise in its export of high-tech products which has generated concerns, and from time to time, trade sanctions, in the US and other developed countries. This phenomenon raises a set of questions: what are the forces that shape the international division of labor of different countries in the global production network? Does the relative position of a country in the international value-added chain embody the

national industrial competitiveness in the international market? What is the position of China's high-tech industry in the global value chain? It is obviously too simple to answer these questions based on a country's output of high-tech products or its international trade volume. Using China's integrated circuit (IC) industry as an example, this study aims at exploring the international division of labor in IC industry, analyzing its value added and technological capabilities of each production stage, and investigating the forces that shape the pattern of industrial ecology at each stage of the value chain, with a particular focus on China.

The Value Chain and Industrial Upgrade in IC industry

The value chain refers to a series of production stages from raw materials supply to manufacturing and processing, and to marketing and product services. It also includes supporting sectors including research and development, human resources, strategic planning, and etc., all within a vertically integrated enterprise (Michael Porter, *Competitive Advantage*, 1985). Along with the development of the international outsourcing business and the globalization of the manufacturing network, the value chain has broken the boundary of one single enterprise and evolved into a global value chain (Gereffi, Zhang Hui). Industrial upgrade usually take place in four forms, namely process upgrade, product upgrade, functional upgrade and the overall upgrade of the value chain (Humphrey & Schmitz, 2000). Through enhancing the internal efficiency and improving the process technology, an enterprise realizes its process upgrade; through launching new products or improving outdated ones, it realizes the product upgrade; through switching to high value-added stages (such developing from manufacturers to designers or technology providers) by developing new capabilities and core competence, it realizes functional upgrade; and finally, when the value chain has completely upgraded to a new one, it realizes the overall industrial upgrade, such as the transformation of the traditional pharmaceutical industry into the bio-pharmaceutical one.

Previous researches have found that international division of labor in high-tech industry typically start with labor intensive and low value-added segments of high-tech industries, where developing countries typically have cost advantages. Such global industrial transfer and international division of labor would upgrade to higher stages on the value chain when having developed certain processing and manufacturing capabilities, thus realizing the overall upgrade of the industrial chain.

The logic it follows is that the industry in one country, through the manufacturing of products at lower stages of the value chain and technological assimilation, is able to gradually internalize it as local technology and upgrade it to higher levels. However, unlike elements such as labor or capital, technology will not spread from a higher value chain to a lower one or from the higher end to the lower end of the same chain. It is because on the one hand that technology is materialized into production elements such as machinery and equipment, and the transfer of machinery and equipment will not automatically improve the recipient's understanding and application of technology; on the other hand, technology is held by the multinational companies (transferor) in the form of patents or business secrets, which would cause enterprises in the hosting country higher costs for technology acquisition, incur local enterprises' long-term dependence on overseas technology and even hamper technological advance in the hosting country (Kokko, 1994[1]; McIntyer, 1986[2]; Peng Jisheng, 2003[3]).

International Transfer of the IC Industry

The history of the IC industry is connected with both industrial structure and international transfer. Leading semiconductor enterprises were initially all integrated device manufacturers (IDMs). After the 1980s, spinning off one after another from the mainstream industry, IC packaging and testing and IC manufacturing developed into independent packaging and testing factories and foundries and a large number of fabless companies consequently sprouted. Then the spun-off packaging and testing industry and manufacturing industry were transferred to Asia where labor cost is low and resources are cheap, thus realizing the global division of labor of the IC industry.

International transfer of the IC industry follows the path from the lower to the medium and higher ends of the value chain. Located at the lower end of the industrial chain, the packaging and testing industry is labor intensive and low in technological threshold. In the 1970s, it was first transferred to Asian countries such as Japan and Korea. With the rising labor cost in these countries, it was gradually transferred to Malaysia, Philippines, and China, etc. from the 1980s and the 1990s. Now, 80% of the global IC packaging industry is located in Asia. Since the 1990s, America, Japan and other major semiconductor powers have started to transfer their manufacturing industry abroad while retaining at home high-end stages of the value chain such as research and design. The IC design industry is knowledge intensive with its core technology represented by both the encoded technology such as block patents and

design tools and tacit knowledge. Skilled system IC designers usually take ten or more years of development experience. It is just because of this fact that developed countries hold a solid grip on the advantage in the IC design industry with their patent strategies and advantageous human resources. Currently, the US is maintaining its lead in IC design with 80% of the world total both in the number of fabless companies and total sales.

Table 1 lists the interrelations among the factor features, technological forms and international transfer of the IC industry.

Table 1 Factor Features, Technological Forms and Transfer of the IC Industry

Value Chain	IC Design Industry	IC Manufacturing Industry	IC Packaging and Testing Industry
Value Added	High	Relatively High	Low
Factor features	Knowledge Intensive	Technology and Capital Intensive	Labor Intensive
Technological Forms	Encoded Knowledge Tacit Knowledge	Embodied Technology Knowhow Technology	Embodied Technology
International Transfer	Not yet transferred with a very wide technological gap	Transferred with one to two generations of technological gap	First transferred with a narrow technological gap

During the international transfer of IC industry, some countries and regions, such as Japan, Korea and Taiwan, have not only set up a complete IC industrial chain gradually, but also acquire proper technological capability for industrial upgrade, thus becoming global leading IC powers. In some other countries and regions, such as Malaysia and Philippines, however, the technology and scale of IC industry are still too insignificant to mention.

The IC Industry in China

China’s IC industry has started to introduce technology and production lines since the 1970s, but only to find itself stuck in the vicious cycle of introducing but lagging behind without exception for every generation of the new product, thus missing the

golden period of development for the international IC industry in the 1970s and 1980s.

Since the year 2000, with the promulgation of *Document No.18* as the main policy support, China's IC industry has seen tremendous changes in both production capacity and technical level. With the door opened by *Document No.18* to foreign capital, a batch of IC manufacturing enterprises represented by Semiconductor Manufacturing International Corporation (SMIC) have started operations in China. At the same time, other stages of the value chain of the IC industry such as the chip design industry and the packaging and testing industry have also seen rapid development. Figure 1 shows the tremendous rise in China's IC production volume before and after the year 2000. (In consideration of the construction cycle, the rise in production volume would appear in 2002).

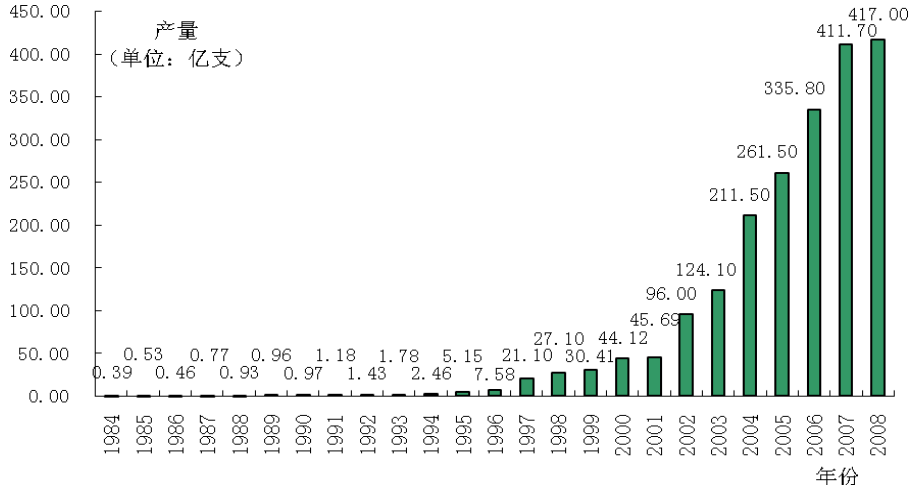

Table 1 IC Production Volume in China (between 1984 and 2008)

Source: The data is complied from *History, Current Status and Prospects of the IC Industry in China* written by Chen Wenhua, *Semiconductor Technology* No.3 issue, June, 1997, *Yearbook of the Electronics Industry*, and *Yearbook of the Information Industry* (1993-2008)

From 2000 to 2007, the total volume of output of Chinese IC manufacturing sector rose from 4.4 billion to 41.17 billion, at an average annual growth rate of 37.6%. And the total output value of IC industry (including design, manufacturing as well as packaging and testing industries) grew from 18.6 billion Yuan to 124.6 billion Yuan, at an average annual growth rate of 31.3%. Both the two indicators are far above the global average of IC industry. Thus, China has become a paradise for investment in the world's IC industry.

Has the IC industry in China formed its complete industrial chain? Whether the scale expansion of the IC industry in China since the year 2000 has brought the technological upgrade? What motivates and who leads the upgrade of the IC industry? How does the pattern of industrial ecology composed of different investment subjects influence the formation of technological capabilities and international division of labor of this industry? Answers to these questions are conducive to our understanding of both the position and the function of China's high-tech industry in the global value chain and international division of labor.

II. The Position of China's IC Industry on the International Industrial Chain

China's IC Industrial Chain

The domestic IC industry, which is different from the international IC industry, has gradually formed an industrial organization in which the three segments of the industry are separated. A large number of IC manufacturers which have introduced the large scale IC production line adopt the form of Foundry, an internationally popular production model. As a result, the auxiliary IC design enterprises and the packaging and testing companies have also grown up. In comparison, almost all the key companies in the Chinese IC industry previously were IDMs, except Hua Hong in Shanghai. The sales income and the growth rate of Chinese IC industry by sector from 2000 to 2008 are shown in Table 2.

Table 2 Sales Income of Chinese Integrated Circuit Industry by Sector (2000-2008)

(Unit: 100 million Yuan)

Year	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
Design Industry	9.8	14.8	21.6	44.9	81.8	124.3	186.2	225.7	235.2
Manufacturing	48	27.7	33.6	60.5	180	232.9	323.5	397.9	392.7
Packaging&Testing	128.4	161.1	213.3	246	283.5	344.9	496.6	627.7	618.9
Total	186.2	203.6	268.5	351.4	545.3	702.1	1006.3	1251.3	1246.8

Data Source: *China Yearbook on IT Industry* (2001-2008)

From 2001-2007, a remarkable change had taken place in the structure of Chinese IC industry: the proportion of the packaging and testing industry in the IC industry

decreased from 79% to 50%, that of the design industry increased from 7% to 19%, and that of the manufacturing rose from 14% to 31%. The ratio among the design industry, the manufacturing and the packaging and testing industry in China is about 2:3:5. There is still some way to go as compared with the balanced ratio of the international IC industry - 3:4:3. The proportion of the design industry is relatively low, while that of the packaging and testing industry is too high. The industrial chain formation of the IC industry in China is shown in Fig. 2:

Fig. 2 Industrial Chain Formation of China's IC industry (2000-2008)

The Position of Chinese IC Industry in the International Division of Labor

An international division of labor has been formed in the IC industry. About 80% of output value of the IC industry is created in America, while over 80% of the IC manufacturing and the packaging and testing industry is distributed in Asia. Chinese IC industry has also deeply integrated into the global IC industrial chain. Among the industries, the packaging and testing industry is the first transferred to China. Many large factories in the world, such as Intel, AMD, STMicron and Toshiba, have founded packing factories in China; since 2000, the growth in the IC manufacturing has mainly come from overseas investment and offshoring; and the IC design industry mainly serves for domestic demand, of which its scale is limited though making a rapid growth.

(1) IC Design Industry

The IC design industry is in the upper reaches of the IC industrial chain, enjoying a high industrial added value. In the world, there are about 600 Fabless companies with certain scale, and 476 companies among them are located in America, of which

the sale volume accounts for about 80% of the global sale. Chinese Taiwan ranks second, accounting for less than 20%. And other areas in the world, including Japan and Korea, all make up only a small percentage in the IC design industry, i.e. Chinese mainland only accounts for less than less than 3% in the IC design industry.[5] In 2008, the sale volume of the top 10 domestic IC design enterprises was 9.402 billion Yuan in total, which was only equal to the ninth of worldwide Fabless (see Table 3, Table 4).

Table 3 Sales volume of Top 10 IC design enterprises worldwide, 2008

IC design company	***Sales (100 million US dollars)***
Qualcomm – QCT	64.77
Broadcomm	46.58
Nvidia	34.25
Marvell Semiconductor	29.51
MediaTek	27.55
LSI	26.77
Xilinx	19.06
Avago Technologies	16.65
Altera	13.67
Sandisk – OEM Division	10.30
Total	289.11

Data Source: GSA

Table 4 Sales volume of Top 10 Chinese IC design enterprises, 2008

IC design company	***Sales (100 million US dollars)***
Hisilicon Technologies	4.53
CIDC	2.11
Datang Microelectronics	1.22
Hangzhou Silan Microelectronics	1.19
ACTS	0.99
SEMICO	0.91
HHNEC	0.90
VIMC	0.91

Beijing Tongfang Microelectronics	0.58
NEC Electronics (China)	0.41
Total	13.76

Data Source: China semiconductor Association (at the exchange rate on Dec. 31, 2008, ￥6.8346 = US$1)

(2) Manufacturing Sector

Due to the notable scale economy in IC manufacturing sector, profits can be made only if the monthly production amount in one production line remains at 50,000. The domestic design market based on small-scale ASIC chips can not meet the capacity requirements of the manufacturing sector. Therefore, the IC manufacturing sector, contrary to the IC design industry which serves for local market, mainly meets the needs of foreign countries. For instance, in 2007, domestic IC output was 5.87 billion and sales volume was 5.59 billion, in which export reached 4.41 billion, accounting for 78.9% of the total sales.

In 2008, Chinese IC manufacturing accounted for 31% of the whole IC industry sales. Among all IC industries overworld, the SMIC in China ranked No. 4, HuaHong-NEC and He Jian ranked No. 8 and No. 9, respectively. Besides, GSMC and ASMC ranked No. 11 and No. 16 respectively (see Table 5).

Table 5 Top ten Pure-Play Foundry Companies overworld, 2008

Ranking	***IC Manufacturing Enterprises***	***Sales (100 million US dollars)***
1	TSMC	105.56
2	UMC	34.00
3	Chartered	17.43
4	**SMIC**	13.54
5	Vanguard	5.11
6	Dongbu Hitek	4.90
7	X-Fab	4.00
8	**HHNEC**	3.50
9	**He Jian**	3.45

10	SSMC	3.40
11	**Grace**	3.35
12	Tower	2.52
13	Jazz	1.90
14	Silterra	1.75
15	**ASMC**	1.49
16	Polar Semiconductor	1.10
17	Mosel-Vitelic	1.00
	Total	208

Note: Chinese enterprises are in bold type. Data Source: IC Insights

By considering pure-play foundries and IDM foundries comprehensively, the rank in Chinese IC manufacturing industry can be found, which is shown in Table 6:

Table 6 Top 10 Chinese IC Manufacturing Enterprises, 2008

IC Manufacturing Enterprises	***Sales*** ***（100 million US dollars）***
Wuxi Hynix – STMicroelectronics	17.86
SMIC	13.61
HHNEC	6.85
CR Microelectronics	6.65
GSMC	2.12
SG-NEC	2.10
He Jian	1.96
TSMC	1.61
Jilin Sino-microelectronics	1.53
ASMC	1.37
Total	55.65

Data Source: China semiconductor Association (at the exchange rate on Dec. 31, 2008, ￥6.8346 = US$1). With different statistical criteria, data in Table 6 is slightly different from that in Table 5, possibly because the non-manufacturing businesses of some enterprises are also included in the statistics.

(3) The Packaging and Testing Industry

The packaging and testing industry is labor intensive industry, which is the first IC industry transferred abroad from some developed countries, such as America, and its investment is usually between 50 million and 100 million dollars. In recent years, the packaging and testing industry is mainly distributed in Asian countries, such as Japan, Malaysia, Chinese Taiwan, Philippines, Chinese mainland and Korea, and its output value accounts for about 80% in global semiconductor packing industry. Chinese mainland makes up 10% of the global packaging industry.

The sales volume of Chinese IC packaging and testing industry reached 62.77 billion Yuan in 2008, accounting for 50% of gross domestic IC product. However, Chinese enterprise did not find a place in the worldwide top 10 packaging and testing companies (see Table 7):

Table 7 Top 10 IC Packaging and Testing Companies Worldwide, 2008

IC Packaging and Testing Enterprises	***Sales (100 million US dollars)***
ASE Group	29.98
Amkor Technology	26.59
SPIL	19.19
STATS-ChipPAC	16.58
Powertech	9.90
UTAC	7.11
ChioMOS	5.40
KYEC	4.99
Carsem	3.70
Unisem	3.52
Total	126.96

Data Source: IC Insights

The businesses of domestic packaging and testing factories mainly come from abroad. For instance, in 2007, the total product of Chinese IC packaging and testing industry was 12.15 billion. In a breakdown, export stood at 11.04 billion, accounting for 90.0%. By the end of 2007, there were 74 IC packaging and testing enterprises with certain scale at home. Among them, 21 companies were local enterprises or domestic-holding enterprises, and the rest companies were all foreign-capital enterprises and joint ventures. Table 8 shows the sales volume of China's top 10 IC

packaging and testing enterprises. Among the listed enterprises, only Jiangsu Xinchao and Nantong Fujitsu are domestic-funded or domestic-holding enterprises.

Table 8 Top 10 Chinese IC Packaging and Testing Companies, 2008

IC Packaging and Testing Enterprises	***Sales (100 million US dollars)***
Freescale Semiconductor(China) Ltd	16.98
Qimonda Technologies (Suzhou) Co., Ltd.	12.58
RF Micro Devices(Beijing) Co., Ltd	6.59
Jiangsu Xinchao Group	5.84
Shanghai Panasonic Semiconductor Co., Ltd.	5.72
Shenzhen STS Microelectronics Co., Ltd.	5.19
Renesas Semiconductor (Beijing) Co., Ltd.	4.22
Nantong Fujitsu Microelectronics Co., Ltd.	3.89
Infineon Technologies (Suzhou) Co., Ltd.	3.39
Samsung Electronics (Suzhou) Semiconductor Corporation	3.20
Total	67.60

Data Source: China semiconductor Association (at the exchange rate on Dec. 31, 2008, ￥6.8346 = US$1). It seems that domestic IC packaging and testing enterprises shall enter the rank of global top 10, as compared with Table 7. However, it is difficult to explain the data. The writer inferred that the output of foreign-owned packaging and testing enterprises at home was included in their parent companies during international ranking, and other businesses were included in the sales volume of domestic local companies.

In general, the Chinese IC industry, after 10 years' of rapid growth, has become a complete industrial chain, including design, manufacturing as well as packaging and testing, and the industrial structure has become increasingly reasonable. However, its overall scale, accounting for less than 5% of the world's IC total output, is still small. In China's domestic IC market, 80% of demand still depends on import.

Secondly, the growth of Chinese IC industry benefit directly from global division of labor. In particular, over 80% of sales from the IC manufacturing sector as well as the packaging and testing industry depend on export. It is different for the IC design industry. Developed countries will not take the initiative in transferring the IC design industry owning to its highest added value. Chinese IC design industry does not have the characteristic of undertaking global division of labor. Instead, it mainly serves for

complete-system vendors at home, and shows the development potential of independent innovation.

At last, the inner link of Chinese IC industrial chain is still weak. And the export-oriented manufacturing, packing and testing will be affected by the international market easily. The IC design industry caters to the demands of the domestic market, and satisfies, to some extent, the productivity of low-end IC manufacturing as well as packing and testing at home. The development of IC design industry is the basis and primary driver for the overall upgrade of the IC industrial chain in the future.

III. Technological Level of China's IC Industry

III. Chinese IC Industry's Technology Capacity

It can be seen from the analysis on industrial chain that over 80% of Chinese IC manufacturing and packaging and testing industries is for export. That's to say, Chinese IC industry has deeply entered the international division of labor of the IC industry. Unlike the IC industry of Japan and Korea, Chinese IC industry has not formed a functional upgrade between the links of the industrial chain as well as an upgrade of the industrial chain as a whole. Instead, the links have been embedded into the international market, and completed process upgrade and product upgrade respectively. Why? In order to answer this question, we shall look into the technology sources of various links and the driving force for the upgrade.

(1) IC Design Industry

As mentioned above, Chinese IC industry has grown up since 2000. Its development bottleneck is mainly the shortage of talents as well as the restriction of chip design patents, IPs and EDA Tools. Therefore, the first batch of IC design companies at home basically fall into two categories: one is small enterprises founded by returned scholars who have work experience in similar enterprises abroad and design patent of chip products, especially ASIC chips, such as chip for hearing aid, chip for cell phone as well as audio and video processing chip etc. A good sensibility to the final consumption market is required for the development of ASIC chips which directly serve for various consumer electronic products. However, the requirement on chip's line width and integration level is relatively low, so are technical threshold and

patent barrier. But single-typed ASIC chip is usually in small demand, like thousands of chips, so that the unit cost for R&D and Manufacturing is very high. Thus, it is difficult to reduce cost by scale economy.

Beijing Vimicro Corp. is an outstanding one among the enterprises of returnees. This corporation was founded by a body of doctors who had studied in America, such as Deng Zhonghan and Yang Xiaodong, in the Zhongguancun Science and Technology Park in 1999, with the direct investment of the Electronic Industry Development Fund and the policy support from the Department of Science and Technology, working at the R&D, design and industrialization of digital multimedia chip. In Nov. 2005, the Vimicro Corp. was listed on NASDAQ, thus becoming the first Chinese IC design corporation listed on NASDAQ. The technologies of the Vimicro Corp. are mainly developed independently. About 20% of its sales volume is used for R&D. This corporation has applied for more than 1,300 patents at home and abroad, among which 85% is patent of invention. In addition, it also owns the independently developed trademark, copyright, literary property and IC layout design etc. During its technological development, government departments, such as the Development and Reform Commission, the Ministry of Information Industry as well as local governments, have extended financial help, which amounts to about 68 million Yuan, accounting for about 10% of its R&D investment. At present, the company's multimedia processing chip for phone, core chip for digital camera and chip for surveillance camera have occupied the domestic mass market.

The other type refers to the IC design companies established by domestic scientific research institutions and state-owned enterprises, which is larger in scale, and specializes in the development of general- purpose chips , such as CPU and memory chip. General- purpose chips are more integrated and modularized, and their patented technologies are monopolized by foreign business barons, such as Intel, AMD and NEC, so that it is very difficult for development. However, due to the great strategic significance of general- purpose chip in economy and national defense, domestic scientific research institutions and state-owned enterprises have never given up the technical exploration into this field. For instance, the "Loongson" series product released by the BLX IC Design Corporation, which is based on the R&D team of the Institute of Computing Technology, CAS, is just a self-developed CPU. It is primarily used in government branches, defense industry enterprises and local microelectronic enterprises (they have been further supported by the government

owning to the “Loongson” CPU core). China Integrated Circuit Design (Group) Corporation Limited (CIDC for short) is another large IC design company at home, which is a state-owned enterprise. Its predecessor is the research institute of original Ministry of Electronics Industry. CIDC’s chip products include the high volume products purchased by the government, such as chip for social security card, chip for tax control and chip for Enterprise Code Certificate. Meanwhile, CIDC is also China’s leading design company for security chip, which is widely used in defense and finance departments.

Therefore, the technologies of the IC design industry are mainly based on independent innovation. In fact, the independent innovation is “passive”, because the technology of chip design greatly attaches to human capital and patented technology, and is hard to be transferred from abroad. However, the rapid development of the IC design industry after 2000 has mainly benefited from three factors: (1) the vigorous growth of local consumer electronics products, such as home-made cell phone and cars (motor electronic); (2) the push from government on technological innovation and government procurement; and (3) the combination of the technological capability accumulated by domestic large research institutions over a long time with the market demand.

(2) IC manufacturing industry

The techniques of IC manufacturers are mainly embodied in three aspects: (1) Materialization of the manufacturing processes on production equipment, including software provided by equipment providers and general solutions to services such as process menu, process control and process integration; (2) The technology licensing acquired by foundries from high-end customers, which is embodied in the technological level of products; (3) Process technologies and organization capabilities embodied in process management, quality control and the strategy for intellectual properties.

The IC manufacturing industry of China has been relied on international production lines ever since 1970s. Before 2000, the dominant IC companies in China are IDM companies which introduced chip products, such as color TV chips and memory chips, along with production lines. After the product renewal, the enterprises remained no power to develop new products, which resulted in idle production lines and serious loss. New IC companies founded after 2000, such as SMIC, Hejian, Grace, Wuxi Hynix-ST and TSMC (Shanghai), are all pure-play foundries; IDM companies

founded before 2000, such as HH-NEC and ASMC, also introduced new production lines to compete for international foundry businesses.

The technological capability of domestic IC manufacturers has been promoted greatly through the international foundry businesses. Taking SMIC for example, 0.25-micron processes were adopted at first; in 2001, SMIC acquired the 0.18-micron standard logic process technology and corresponding rights of patent using from the Chartered Semiconductor Co. (Singapore), and has been licensed by Toshiba (Japan) for using low-power SRAM and obtained orders. In 2002, SMIC acquired the technique of producing 0.14-micron standard memory chips (DRAM) from Infineon (Germany). Through studies, SMIC extended the 0.14-micron technique to 0.15-micron and 0.13-micron level. The 90 nano-technique of SMIC was licensed by the Texas Instruments (TI), Infineon and ARM, etc. Recently, SMIC signed a 45nm-technique license agreement with IBM. IBM transferred the 45-nm low-consumption and high-speed bulk CMOS technique to SMIC, which is so far the most advanced mass-production technique.

Apart from technology licensing, SMIC carried out self-development and cooperative development so as to gain technology independence. In China, SMIC established close technological cooperative relationships with Beijing University, Tsinghua University as well as the Chinese Academy of Sciences and other institutions, and even undertook basic research projects of the government. For example, the 973 projects and the key planned research projects launched in 2009 include some undertaken by the Shanghai Company of SMIC. [6]

Generally speaking, the technological capability of domestic IC manufacturers is directly benefited by equipment providers and high-end customers, which also promote their marketing and organizing capabilities. Domestic IC companies presently acquire technologies, funds and talents throughout the world for resource integration, utilization and redevelopment, and a benign circle has been formed. For instance, companies will not buy in a production line as a whole for introduction, but purchase high-tech key equipment in global scale and build their own production lines. Based on understanding, comparison and assembly of manufacturing equipment, domestic companies have formed corresponding technological capabilities from their structures. Besides, since foundries have to compete for foundry orders in the global market, the marketing abilities of domestic IC companies are developed. Despite all of these, international semiconductor superpowers generally build technical alliance

to develop new-generation techniques and share the expenses and risks of research and development due to the rapid development of international semiconductor techniques and the huge investment on research and development. As for Chinese companies, they are yet to be placed in the alliance of advanced technologies.

(3) Packaging and testing industry

Compared with the IC design industry and the IC manufacturing industry, the situation of the packaging and testing industry is much better. Owing to relatively loose technical restricts and control plus less overall investment, the earlier investment of numerous international IDMs in China basically centered the field of packaging and testing. Intel, ST, Infineon, Renesas, Toshiba and other major international semiconductor providers have presently laid investment in Shanghai, Wuxi, Suzhou, Shenzhen and Chengdu, etc. to build packaging and testing bases. Fourteen out of the globally top 20 semiconductor providers have found joint or self-owned packaging and testing companies in China, which have become the leading ones in Chinese packaging and testing industry in terms of both production scale and technical standard.

The foreign-owned IDM packaging and testing companies in China basically serve for their parent companies. For instance, 100% of the products of Intel are exported, and 99.6% of Freescale products are exported. Middle and high end products dominate the orders sent to foreign-owned OEM packaging and testing companies, while those of domestic packaging and testing companies are basically conventional low-end products such as DIP and SOP.

In recent years, the development of the uprising Chinese IC design industry and IC manufacturing industry has given rise to effects of promoting the packaging and testing industry in China. Companies from the Chinese Mainland have made some break-through achievements in advanced packaging and testing techniques such as BGA, CSP and MCM, and lead-free packaging and testing techniques like QFN have been applied to mass production. The Nantong Fujitsu Microelectronics Co., Jiangsu Changdian Electronics Technology Co.,， Tianshui Huatian Co.,. and other companies have made great achievements in the development and application of advanced packaging modes such as PGA, BGA, CSP and MCM. As for foreign-owned companies, BGA, CSP, MCP, MCM, MEMS and other packaging techniques have been introduced for mass production. The overall technological capability gap between the Chinese packaging and testing industry and the international level is

decreasing gradually.

Generally, the technological gap of Chinese IC industry against the world advanced level is shrinking; particularly, the technologies of the IC manufacturing industry and the IC packaging and testing industry have been ranked in the international mainstream. In terms of the sources of their technical capabilities, however, the techniques of the Chinese IC design industry are based on domestic self-development, while those of the IC manufacturing industry and the IC packaging and testing industry stem from other countries.

During the international transfer of IC industry, some countries and regions, such as Japan, Korea and Taiwan, have not only gradually set up a complete IC industrial chain, but also acquired proper technological capability for industrial upgrade, thus becoming global leading IC powers. In some other countries and regions, such as Malaysia and Philippines, however, the technology and scale of IC industry are still too insignificant to mention. So then, what is the determining factor for industrial upgrade in international industrial transfer?

IV. Ecological Pattern of China's IC Industry

The scale enlargement, technical progress and depth of participation in international division of labor of Chinese IC industry after 2000 are very impressive. Under the conditions of global industrial division, are the industrial scale and technical capability of one country's high technology industry representative of the industrial competitiveness of that country?

Two Foreign Capitals: Financial Investor and Strategic Investor

As for foreign capitals of high-tech industry, it is necessary to distinguish the two investors: one refers to capital investors coming from the financial market, including stock market and private fund, aiming to get the high value-added profits of high-tech industry. The owner of the capital pays attention to enterprise's business performance, but usually does not involved in the enterprise's operation strategy and technological capability building. Some IC manufacturing enterprises, such as SMIC, GSMC and He Jian, belong to this class. This type of enterprises, which have grown up locally, pays attention to the development and accumulation of their own technological capabilities, and gradually forms the endogenous driver for technical development and industrial upgrade on the basis of market demand and their own capabilities. In addition, with the continuous development of enterprises, they will attract new

investors to participate in, and then the influence of investors on enterprises will be further decreased. Therefore, the enterprises which take financial investors as the investment subject, in terms of the ecological pattern of industry, shall be perceived as localized component.

The other type of investors refers to the strategic investors in transnational enterprises. The transnational enterprises, based on their own scale enlargement and the global logistic strategies, transfer their manufacturing sectors and packing and testing sectors to China, so as to reduce cost, enhance production capacities and expand market share. The strategic investors intervene in the strategic management of their companies in China in the form of single venture or joint venture while controlling interest. Both their business planning and technical capability building are subject to the unified plan of their parent companies, but only have a weak tie with local market. Under the conditions of global market tightening or corporate strategy adjustment, the factories in China may be stopped, closed or transferred at any moment. This kind of enterprises does not belong to the localized component in the ecological pattern of industry.

Indigenous Companies vs. MNC Branches in China IC Industry

Thus, in view of the investment feature of the high-tech industry, Chinese IC enterprises can be divided into two classes, which are indigenous companies and MNC branches. Accordingly, the ecological pattern of IC industry has the following features:

(1) The top 9 out of the Chinese top 10 IC design enterprises are indigenous companies, and their incomes account for 97% of the gross earning of the top 10. For instance, No. 1, the Shenzhen Hisilicon Technologies Co. Ltd, which is the original Huawei IC Design Center, is headquartered in Shenzhen, and has design branches in Beijing, Shanghai, Silicon Valley and Sweden. And No. 10, the NEC Electronics (China) Co. Ltd is a wholly foreign-owned MNC branch, which works at the IC design, development, sales and technical support in China for Japan’s NEC Corporation.

(2) Among Chinese top 10 IC manufacturing enterprises, 8 are indigenous companies, and their incomes account for 65% of the gross earning of the top 10. Among the top 10, Wuxi Hynix-ST and TSMC (Shanghai), which are the world’s leading chip manufacturers, belong to the type of transnational enterprises with

strategic investors. TSMC's chip foundry production accounts for near 50% of the world's foundry. However, under the influence of 2008's financial crisis, TSMC has reduced the production in Chinese factories rapidly, which accounts for less than 1% of that in Taiwan.

(3) Chinese IC packing and testing industry has basically been dominated by foreign capital. Among the top 10, there are 5 wholly foreign-owned companies, 8 foreign holding companies, and only 2 indigenous companies, which are Jiangsu Xinchao and Nantong Fujitsu. And the income of the two indigenous companies only accounts for 14% of the total earnings of the top 10. Besides, indigenous packing and testing companies are also at a disadvantage in terms of technical capability and market competition.

In general, under the bright light of rapid growth, Chinese IC industry has shown an ecological pattern which mingles hope and fear. On one hand, the design industry, which plays a leading role in the industrial chain with high added value, has built proper technological capability for localization based on local market demand, and initially had the endogenous power and capability for technical upgrade. Meanwhile, the IC manufacturing industry, as the main body of the industrial chain, benefits from new capital and enterprise operation mode. The localized manufacturing productivity has developed, and the technology basically approaches the international mainstream level. On the other hand, the IC packing and testing industry, of which the product makes up a half of China's IC industry, is dominated by multinational corporations. Most productivities and technologies are controlled by MNC branches. Its localization is weak. With the weakening of costs advantages in relation to labor and resource, predictably, this industry will be transferred to South-East Asia, where has more costs advantage, in the future.

V. Conclusions

Firstly, the rising of China as a big producing country for high-tech products is capturing the world's attention. We shall carefully analyze the technological level and ecological pattern of China's high-tech industry behind this scale enlargement and study the development trend of the industrial chain based on the localization of production, technology and market. The industrial chain with upgrade potential shall not only have a comprehensive industrial structure, but also have the following two factors:

(1) The connection between all production stages of the industrial chain;

(2) The endogenous technological capability of indigenous companies.

Secondly, when China's high-tech industry participates in the international division of labor, only a few enterprises acquire the endogenous power for technology upgrade. So, what kind of enterprises will be able to move towards the high end of the value chain in the international division of labor? The following factors are necessary:

(1) Indigenous companies, instead of MNC strategic branches;

(2) Chinese Returnees' team or national research institutions and state-owned enterprises with a long-term technological accumulation;

(3) Government support and favorable policies on technological innovation and industrialization.

Thirdly, high-tech industry is generally characterized by high investment costs and high risks. The international capital market, including international private funds, is of the utmost importance to the industrial development. As for the high-tech industry under the support of the international capital market, it cannot effectively disclose how international division of labor can help transfer the technology in the host country by simply dividing the capital property as domestic or foreign. In contrast, it is of great practical significance to analyze if it belongs to a MNC strategic branch.

In this study, the analysis on the participation of the high-tech industry in the international division of labor is restricted within the IC industry only. Relevant researches on other industries are welcomed.