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TECHNOLOGY DIFFUSION AND POWER TRANSITION: THE CASE OF THE SEMICONDUCTOR INDUSTRY IN EAST ASIA

Abstract: *The semiconductor industry is an excellent illustration of the interaction between technology diffusion and power transition. Since the 1960s, there have been three large waves of technology transfer as well as industry transfer in East Asian countries' semiconductor industry, where the production network acted as an essential nexus. International technology diffusion, whose channels consist of international trade and foreign direct investment, plays a primary role in the formation of the semiconductor production network in East Asia, which has a profound influence on shaping the international power structure. However, the reshaping power structure always attracts the technology exporter's attention and provokes power competition between the dominant state and the rising power, which in turn casts negative influences on international technology diffusion. Nowadays, the third wave of technology transfer in this field has been ongoing for decades between first-movers and China, while the power competition and the COVID-19 pandemic disrupted the process, which will greatly influence the power distribution in the field of the semiconductor industry and the international power structure.*

Keywords: *International Technology Diffusion, Power Structure, Production Network, Power Competition.*

Introduction

The ongoing global chip shortages, which started in 2020 during the COVID-19 pandemic and would definitely last longer than expected, have become a critical choke point not just for economic activities such as the manufacturing of medical devices, electronic products, and so on, but also for national security. The current crisis in the semiconductor supply chain, which attracted the attention of the great powers, spurred industrial relocation with the stimulation of industrial policies designed by the major powers. In the 20th century, there were two large waves in the semiconductor industry relocation: the first wave was during the 1950s to 1970s, Japan succeeded to undertake the industry transfer and dominated in the Dynamic Random-Access memory (DRAM) industry for almost a decade; the second wave was initiated from the mid-1980s, Taiwan and Korea as latecomers caught up and built its own advantages in certain segments of the semiconductor industry. These two large waves of global semiconductor industry transfer brought about the collective rise of the semiconductor production networks in East Asia, which shaped the current international production power structure. Each wave of industrial transfer was not only driven by knowledge spillover but also supported by industrial policy.

Since China entered the World Trade Organization (WTO), a new wave of semiconductor industry transfer is showing up, accompanied by foreign capital flowing into China. There are obvious improvements in technology and a move-up in the global value chain of the semiconductor industry. Technology spillovers count, which gradually enhance the competitiveness of Chinese firms in this field and improve the market share of the world semiconductor industry. However, given the state-centric power competition and the COVID-19 pandemic, which heavily damaged the international liberal order as well as the global supply chain, the semiconductor supply chain was deemed the main concern of national security by most countries. The international cooperation of the semiconductor industry based on the global value chain was challenged by power competition, which would definitely bring the global supply chain into chaos. In the context of re-globalization, great powers compete for manufacturing capacity in key fields, which has become a new feature of this era. Industrial policies with the aim of improving the indigenization capacity of the semiconductor industry were designed, which reflected the desires of these countries to secure the supply chain and keep the industrial chain under control. There is no doubt that the production network of the semiconductor industry, which plays a key role in shaping the international production structure, is highly valuable for those countries to achieve their strategic goals.

However, there are few articles focusing on the relationship between technology and the international power structure. Obviously, the production network is the critical nexus between them. Then, what's the relationship between the technology diffusion network and the production network? How could the production network shape the international power structure? And when it comes to power competition, how could it influence the interaction between technology and the international power structure? To answer these questions, it is necessary to trace the brief history of the formation of the semiconductor production network in East Asia and explain how the network contributed to the transition of the international power structure, as well as the relocation of the production network during the power competition. This article will try to figure out the interaction mechanism between the technology and the international power structure.

Interaction between technology and international power structure

Susan Strange points out that the international power structure consists of four different sources of structural powers, namely knowledge, security, finance, and production, which shape and determine the structures of the global political economy, while technology is most important for acquiring relational power and reinforcing other kinds of structural power (Strange 1988, 31). Moreover, Strange holds the point that the technological changes in the knowledge structure have had on the production structure bring about the centralized power in the big transnational corporations, which headquartered in the US. In short, the technological changes have led to a greater concentration of power in one state (Strange 1988, 133). However, in reality, the technology changes not only bring about the concentration of power, but also lead to the power transition, thus it is necessary to figure out the interaction between technology and power structure.

The hinge between Technology diffusion and power transition is the production network: the production network is the basis of the production structure which could be influenced by technology diffusion, the international technology diffusion could bring about the international transfer of the production network, which forms international production center and reshapes the international power structure.

Technology innovation and diffusion shape the international power structure

There are strong correlations between the international production network and technology diffusion. The formation of a production network is always connected with the diffusion of technology. International firms focusing on international trade usually need to build their own supply chains in the host countries with the aim of reducing production costs, which could help the host countries form their complex production networks. Therefore, it is very critical for host countries to join international trade to spur the formation of an international production network and attract foreign direct investment to stimulate the technology spillover.

As for the main channels of technology diffusion, International Trade and Foreign Direct Investment (FDI) played essential roles during the process of technology spillover (Keller 2002, 2004; Branstetter 2006; Poole 2013).

International trade could be divided into two different types: import and export. The import would augment the domestic technology stocks by way of purchasing and utilizing them, as well as imitating the advanced technology, which could help improve the host countries' technology level and spur endogenous innovation (Crespo ed., 2002; Blalock ed., 2007; MacGarvie 2006). Meanwhile, import should be synchronous with export, which could contribute to the formation of a dense production network and facilitate industry transfer. Export could notably improve the productivity and the industrial growth in the host countries through learning-by-export effects (Biesebroeck 2005; Loecker 2007). Moreover, international trade could help the host country join the international supply chain, which is essential for the formation of a competitive production network.

FDI could play a positive role as a channel of international technology diffusion by way of horizontal and vertical FDI spillover, as well as worker turnover, which could potentially generate a positive technology spillover to the domestic firms (Keller 2010, 810-815). Horizontal FDI spillovers refer to the technology learning effects of multinational firms occurring in within-industry firms, especially in high-tech industries, which could generate an increase in firm productivity as well as industrial growth (Haskel ed. 2007; Keller and Yeaple 2009). Vertical FDI spillovers refer to multinational firms purchasing intermediate inputs from local suppliers, which could impose technology requirements and standards on local suppliers and diffuse the technology to downstream firms (Pack and Saggi 2001; Blalock 2002; Javorcik 2004; Blalock and Gertler 2008). FDI counts, not just for the technology diffusion that could help improve the firms' productivity and form a competitive production network, but also because it could create large amounts of jobs and generate tax revenue. FDI spillover through labor turnover is another important way of technology diffusion, which could help transfer technology from the multinational companies to domestic firms (Görg and Strobl 2005).

International power structure counteracts technology innovation and diffusion

Competitive Production Network embedded into the global supply chain, is not just the basis of the international power, shaping the power structure, but also the powerful platform conducive to the industrial upgrading and the technology diffusion, which always spurs the great powers' competition and stimulates the technology innovation and diffusion.

The production network, which is embedded in the global supply chain in the host country, could contribute to technology innovation and diffusion with the method of industrial upgrading. It would be more convenient for firms in the global production network to absorb advanced technology to improve their productivity and complete the primitive accumulation of capital, while simultaneously stimulating their determination to upgrade and lift their position in the global value chain to earn more profits (Gereffi 1999; Krugman 1992; 1994). Consider East Asia: with rapid growth in manufactured exports, the newly industrializing countries (NICs) of East Asia, namely Hong Kong, Singapore, South Korea, and Taiwan, gradually raise participation rates, intersectoral labor transfer, educational levels, and investment rates, which objectively help firms move up in the GVC (Young, 1995).

Technology innovation and diffusion are not just the core elements to drive the changes of international power structure, but the significant causes to spur the competition between the rising power and the dominant power (Drezner 2019; Milner and Solstad 2021; McCarthy 2015; Zhu and Long 2019). In order to keep their status in GVC and satisfy the requirements of the domestic interest groups, developed countries as the dominant power and technology exporter always take actions to block the technology diffusion and deter the industry upgrading or technology innovation of the rising power by all means. Moreover, given that the production center is always separated from the technology-export center, the production network could be the focus of power competition by great powers with the aim of securing and decentralizing the supply chain, even taking actions to crack down on the competitors' network.

Collective rise of the semiconductor industry in East Asia

The United States has dominated the semiconductor industry from the beginning of the integrated circuit (IC) at Texas Instruments in 1958 until the 1980s. The early market demand (1958–1964) was primarily driven by the Department of Defense and NASA, but until 1966, commercial demand had surpassed the federal government's demand for ICs (Moore 1990, 99). ICs' technological improvements have always been motivations for technological revolutions in computers, telecommunications, and other electronics industries: price reductions and performance improvements could help IC products possess abilities for the further development of electronics goods by providing opportunities for new entry and innovation. (Steinmueller 1988, 319). Actually, there have been two large-scale waves of semiconductor industry transfer in history: The first wave was with the rise of mainframe in the 1970s and 1980s, Japan succeeded to develop its own semiconductor industry and catch up with American competitors, gradually dominated the DRAM industry and became the most important international production centre of semiconductor; the second wave was with the rise of personal computer (PC) industry and IT industry in the 1980s and 1990s, Korea replaced the status of Japan's status in the DRAM industry, meanwhile Taiwan succeeded to create a new model-'foundry' and became a competitive role in the world semiconductor industry. In the past, waves of industry transfer, technology diffusion, and power competition played essential roles.

1. The first wave of industrial transfer and Japan's rise

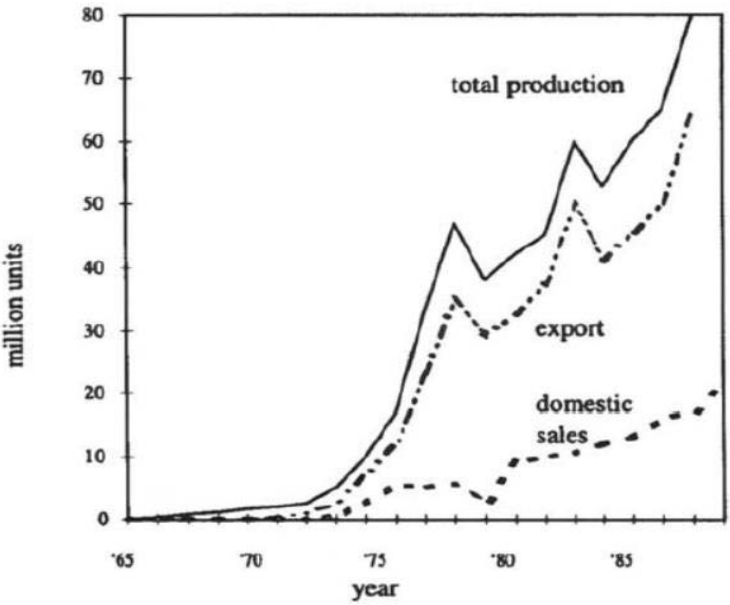
(1) The semiconductor industry is the basis of several industries, e.g., the consumer electronics industry, which could provide the necessary increased market capacity to drive the research and development of the semiconductor industry. As for the outset of Japan's semiconductor industry, international trade, and FDI count.

(2) International trade

International trade played an important role in absorbing advance technology and capturing more world market share to earn more profits, Japanese semiconductor industry start from the early 1950s, of which the import of transistor technology was the sign: in 1953, Morita, the founder of SONY, signed a licensing agreement with

Western Electric to use the transistor in consumer electronics, such as radio sets. The company produced its first transistor radio in 1955 and, two years later, in 1957, its first "pocketable" radio, which initiated a new era of miniaturized radios (Nakayama ed. 1999, 32). In the following decades, the boom of consumer electronics created enormous market demands for the Japanese IC industry, for example, the calculator industry, which has grown to become export-intensive since 1975, contributed a lot to the development of the Japanese IC industry (see Table 1).

Table 1: Growth in sales volume of the calculators from 1965 to around 1985 (Nakayam ed. 1999, 35)



Since the mid-1970s, Japan has gradually grown up and become a major world computer producer, whose domestic production has begun to outstrip imports. Moreover, in Japan, the major computer producers were also IC producers, which shortly grew up to be competitive rivals with IBM in the domestic market (Steinmueller 1988, 326). The rapid growth of commercial demands for DRAM attracted Japanese manufacturers. With the stimulation of the government’s industrial policies, the production of DRAM chips soon surpassed domestic demand, and the export drive began: the share of made-in-Japan chips in the world DRAM market was nil in 1970, then grew to 80 percent in 1988. In the age of 64K DRAM, the Japanese suppliers had established an overwhelming presence in the DRAM market. By the mid-late 1980s, only TI and Micron Technologies remained in the market (Nakayama ed. 1999, 48).

(3) FDI

In the beginning, FDI was restricted by the Japanese government with the aim of protecting its own industry and domestic market. However, there were positive influences on introducing new technologies. In Japan, what stimulated the IC market was Texas Instruments' (TI) investment in 1964, which compelled the Japanese companies to transform their marketing strategies from the transistor to the integrated circuit in 1965. However, in the early stages, FDI was highly restricted by the Japanese government with the aim of protecting the domestic market and producers. Therefore, TI was coerced by the government to open its patents to the public to gain permission to invest in Japan, which help the Japanese firms much easier access to more advanced technology and stimulated the birth of the first Japanese MOS IC in 1967, just two years behind the US (Okada 2000, 67-68). American technology leadership and rising market share stimulated the Japanese companies to develop their own technologies without foreign licenses, such as the development of LSI technology: main IC producers started to develop process technologies by themselves with ambitions of being self-reliant and cutting down patent costs, thus the period of LSI technology contained many indigenous technologies (Okada 2000, 70). While American electronic companies were decimated in the calculator war, Japan drastically reduced import dependence in 1972, which was regarded as a watershed moment for Japanese semiconductor.

Meanwhile, since the government imposed more strict control over the importation of IC units and lifted restrictions on foreign ownership of IC companies (computer use was allowed in 1974), Texas Instruments, Fairchild, and Motorola, which established joint ventures with Sony, TDK, and Alps in the early 1970s, started to conduct independent operations without joint ventures (Okada 2000, 72). Facing more and more fierce competition, Japanese companies try their best to strengthen their competitive edges. Later on, Japanese companies gradually overcame the pressures imposed by U.S. technology dominance and high market share and led the development of a highly profitable area, e.g., the DRAM industry, with the method of cumulative production improvement and technology innovation.

(4) Production network's active influence

With the growing IC market (e.g., the upcoming Mainframe Computer age,) and severe competition, domestic semiconductor companies in Japan gradually formed a production network consisting of multidivisional firms: For the period 1978–1982, nine firms (Matsushita, Mitsubishi, Fujitsu, Fujitsu, NEC, Tokyo Sanyo, Hitachi, Oki, and Sharp) contributed about 90% of the domestic output in the IC industry and reshaped the competition pattern (Kimura 1990, 75). Especially in the IC industry's segment, e.g., the DRAM industry, Japanese companies dominated in this field for several years and successfully overturned US technology dominance. Intel was the first company to invent 1KB DRAM in 1971, and due to the "first-mover advantage," American companies such as Mostek, Motorola, and Fairchild led the development of the DRAM industry for several years. Japanese firms caught up with their American peers in the mid-1970s and gradually occupied 5 of the top 7 companies in the DRAM industry from the mid-1980s to the early 1990s (see table 2).

Table 2: Top Seven IC Firms in the DRAM industry in the World
(Kim and Lee 2003, 1201)

Rank	1975	1978	1981	1984	1987	1990	1993	1995
1	Intel	Mostek	Mostek	Hitachi	Toshiba	Toshiba	Samsung	Samsung
2	TI	TI	Fujitsu	NEC	NEC	Samsung	Hitachi	NEC
3	Mostek	NEC	NEC	Fujitsu	Mitsubishi	NEC	Toshiba	Hitachi
4	NEC	Intel	Hitachi	TI	TI	TI	NEC	Hyundai
5	Motorola	Motorola	TI	Mitsubishi	Hitachi	Hitachi	IBM	TI
6	Fairchild	Fujitsu	NS	Mostek	Fujitsu	Fujitsu	TI	Toshiba
7	NS	Hitachi	Motorola	Motorola	Samsung	Mitsubishi	Mitsubishi	LG

The reasons were various, while the dense production network of the IC industry in Japan established a solid basis for Japan to surpass American peers and dominate the DRAM industry in the 1980s: In 1984, a large scale of investment flowed into the Japanese semiconductor industry, especially in the building of the 64K DRAM generation's factories, which improved the capacity development and competitiveness of the Japanese firms in the generations of the 64K DRAM and accelerated the exit of many American firms during the next generation, the 256K DRAM (Flaherty 1992, 291-292).

(5) Power competition over the production capacity

There was no doubt that the Ministry of International Trade and Industry (MITI) was significant in the development of the Japanese computer and semiconductor industries with its contributions to the import and improvement of technology for domestic firms. MITI funded the Mainframe Computer Project (1972–1976) and the Pattern Information Processing Project (1972–1976), which fostered three Japanese companies (Hitachi, NEC, and Fujitsu) to be serious competitors to IBM; IBM's market share in Japan shrank from 80% in the 1950s to less than 30% by the late 1970s. Meanwhile, MITI released the Very-Large Scale Integration (VLSI) Project (1976–1980), which stimulated the Japanese development of memory chips (Nakayama 1999, 45). The demands created by the mainframe computer drove the development of the Japanese IC industry; with the help of well-structured industrial policies designed by MITI, Japanese semiconductor firms finally caught up with their American peers and dominated the DRAM industry in the 1980s. However, several technology projects created by MITI, like the Supercomputer Project (1981–1989) and the Fifth Generation Project (1982–1991), aroused American attention about national security issues and unfair trade practices, which created years of political disputes.

From the mid of the 1980s, the US Department of Commerce (USTR) initiated a series of section 301 investigations into Japanese semiconductor firms, with the ambition of deterring the Japanese IC industry and restricting its preponderance in the field of DRAM industry. In 1986, after years of political negotiations, the U.S. and Japan finally reached an agreement (the U.S.-Japan Semiconductor Trade Agreement of 1986), in which Japan made a concession: it agreed to improve the share of imports from the U.S. to 20% within five years and established an organization to take charge of this; the manufacturing costs of DRAM and EPROM chips produced by Japanese companies should be reported to the U.S. government to ensure the reduction of unfair trade practices (Nakayama 1999, 48). Power competition between Japan and the U.S. lasted for decades. Under great pressure from the US government and a deteriorating international trade environment, the Japanese IC industry faced great challenges and lost the ability to promote further industry upgrading. In the 1980s, when Japan's semiconductor industry reached its peak, a new wave of industry transfer and relocation of the production network arose in East Asia.

2. The second wave of industry transfer and the rise of Korea, Taiwan, and Singapore

Under the great pressures of power competition with the U.S. and severe market competition with Korea, Japan gradually lost its leading role in the DRAM industry in the early 1990s. Korea, Taiwan, and even Singapore found their own way to develop the semiconductor industry and gradually replaced Japan in this field. Latecomer firms in these countries which succeeded to catch up with the leading firms in U.S. and Japan, highly relied on the acquisition of technological competences by way of various means, such as licensing, contract manufacturing as well as joint ventures (Cho and Mathews 2000, 3). Combined with the governments' industrial policies, the management of technology diffusion was deemed the competitive strategy, even a national strategy, for latecomers in East Asia.

The rise of Korean semiconductor companies, such as Samsung, LG Semicon, and Hyundai, could be attributed to the rapid rise of PC demands, and they overtook the Japanese giants NEC, Toshiba, and Hitachi in the DRAM industry in the 1990s. The success of Taiwanese semiconductor firms benefited from the new business model, "exclusive wafer foundries," which fabricate chips for an increasing number of firms all over the world that could not afford to build fabrication factories, as well as for those IC design giants without the desire to invest huge amounts of capital in quickly updating fabrication facilities. By the second half of the 1990s, Taiwanese firms had entered the memory chip fabrication business and were starting to challenge the Korean and Japanese firms. Moreover, Singapore's success in the semiconductor industry owed much to FDI from the leading firms in the U.S. and other Asian countries. The second wave of industry transfer shaped the current international power structure in the field of semiconductor manufacturing.

(1) International trade

Knowledge transfer, such as technology import, played an important role in the creation of the semiconductor industry in Korea and Taiwan. In the early 1980s, Korean firms like Samsung, Hyundai, and Goldstar entered the production of the IC industry, especially memory chips (DRAM), by importing technology from leading firms in the US or Japan.

Table 3: IC Industry Technologies' Licenses to Korea Firms 1982-1988 (Mathems and Cho 1999, 148)

Company	Year	Technology
Samsung and :		
ITT	1982	Telecom ICs
Micron	1983	64K DRAM
Sharp	1983	CMOS Process
Zytrex	1983	High-speed CMOS process
Zilog	1984	8-bit Microprocessor
Intergraph	1984	32-bit Microprocessor
Exel Micro	1985	16KEEPROM
Goldster and:		
AT&T	1984	Telecom ICs
Zilog	1985	Z80 Microprocessor
AMD	1985	64K DRAM
United Microtek	1985	256K DRAM
Hitachi	1988	1M DRAM
Hyundai and:		
WDC	1984	8-bit 6502 MPU
Vitelic	1985	256K DRAM
Mosel	1985	64K 256K SRAM
Vitelic	1986	1M DRAM
LSI Logic	1985	Gate arrays

Similar to Korea, Taiwan initiated its semiconductor manufacturing in the 1970s by signing agreements with American firms (RCA at the beginning) to import technology and train engineers. Technology was transferred to the private sector when the Industrial Technology Research Institute (ITRI) transferred its VLSI technology to TSMC in 1987. With the assistance of Philips to provide the major technological input and well-trained personnel provided by ITRI, a new era of pure foundries was created (Tung 2001, 271).

On the other hand, outward exports helped both Korean and Taiwanese firms act as major participants in the global IC industry in the fields of production, trading, and investment.

In Korea, it was inevitable for Korean firms to choose an export-oriented strategy due to the limited domestic market demand. The Korean firms with strong competitiveness showed an outstanding growth rate compared with the growth rate of the world semiconductor industry, which contributed to improving the Korean firms' market share and the status of Korea in the global value chain.

Table 4: Current Status of Korea's Semiconductor Industry (US $ million) (Byun 1994, 708)

	1984	1986	1988	1990	1992	Annual Growth Rate (%)
Production (A)	1,268	1,469	3,066	5,104	7,800	25.5
Exports (Korea)	1,250	1,397	3,179	4,538	6,804	23.6
World Market (B)	29,087	30,642	45,017	58,200	65,300	10.6
A/B(%)	4.4	4.8	6.8	8.8	11.9	

The Korean semiconductor production totaled US $8,508 million in 1994, and 90% of this was exported, for 1995, an export ratio of 91%, which made Korean IC (most of them were DRAM) producers successfully compete in the world market on the basis of process innovation and manufacturing efficiency (Kim 1996, 6-7).

As for Taiwan, in the 1980s, the electronics industry, consisting of consumer electronics, telecommunications, and IT, surpassed textiles to become the country's largest manufacturing sector and create huge amounts of exports as well as trade surpluses. The Taiwan semiconductor industry, as an upstream sector, was stimulated by market demands from the electronics industry and gradually saw a boom in both manufacturing and design beginning in the late 1980s.

Therefore, international trade is critical for the semiconductor industry's transfer; it was crucial for Korea and Taiwan, with their limited domestic markets, to join the international trade, which could not only introduce advanced technology from abroad but also provide an enormous overseas market.

(2) FDI

General Instrument Microelectronics' investment in Taiwan in 1966 to operate its IC packaging business could be considered the start of Taiwan's semiconductor industry. Multinational firms like Philips, TI, and RCA started the packaging business, which concentrated on the labor-intensive industry and laid the foundation of the Taiwan semiconductor industry (Liu 1993, 302). Later, Taiwan's industrial upgrading was carried out through a joint venture with international firms in order to capture technology diffusion.

Table 5: Taiwanese DRAM Fabrication Initiatives 1993-1998 (Cho and Mathews 2000, 49)

Date of Production	Company	Technology Transfer source
1993	TI-Acer(ASMI)	Texas Instruments
1994	Mosel-Vitelic	Oki
1995	Vanguard	ERSO
1996	Nan Ya	Oki
1997	Powerchip	Mitsubishi
1998	Winbond	Toshiba
1998	MXIC	Matsushita

For Singapore, the electronics industry plays a significant role in Singapore manufacturing, which mainly relied on FDI, e.g. the semiconductor industry, with the main operations of testing and assembly in the mid-1980s, was upgraded through the multinational corporations' investment in wafer fabrication plants, such as SGS, Hewlett Packard and TECH Semi (Kai-Sun ed. 2001, 48). FDI is an important technology diffusion channel for Singapore, which could help induce the domestic transfer of related knowledge and technologies through local labor training and domestic operations.

Table 6: IC Fabrication Facilities in Singapore 1985-1999 (Cho and Mathews 2000, 52)

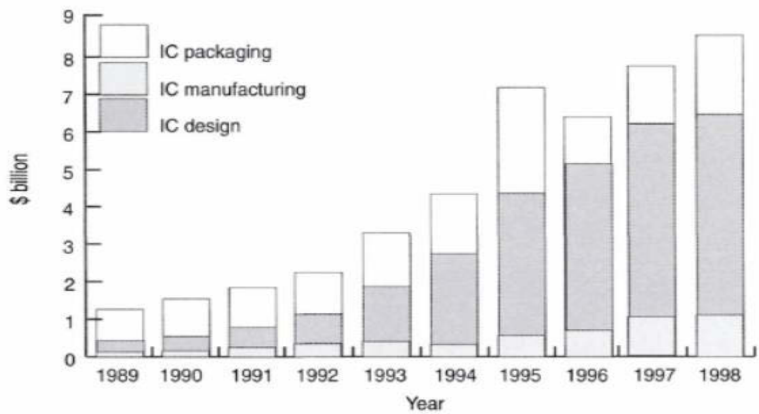
Year	Company	Wafer Size
1985	SGS	6 inch
1987	Hewlett Packard	6 inch
1989	Chartered I	6 inch
1993	TECH Semi I	8 inch
1996	Chartered II	8 inch
1997	TECH Semi II	8 inch
1997	SGS-Thomson	9 inch
1997	Charter III	10 inch
1998	Chartered Silicon Partners	11 inch
1998	Hitachi/Nippon Steel	12 inch
1999	Silicon Mfg Partners	13 inch
1999	Hitachi/Nippon Steel	14 inch
1999	TSMC/Philips	15 inch

(3) Production network's active influence

Except Japan, all the countries in East Asia have entered the semiconductor industry through the investment in the packaging and testing of chips, which is the least value-added and the most labor-intensive, through an industry transfer from American firms. The Korean semiconductor industry was initiated by the investments of Fairchild and Motorola in 1964, as well as the later participants, Signetics and American Micro-Systems; Taiwan's assembly industry was started by foreign investment from TI, GI, and Micro-Systems between 1967 and 1969; as for Singapore, TI and Fairchild contributed a lot to its semiconductor industry's development in 1968 and 1969 (Davis and Hatano 1985, 128–129). Both the firms and their host countries had very strong incentives to move up in the global value chain of the IC industry, from 'back-end' packaging and testing to 'front-end' wafer fabrication and the affiliated activities of wafer production, and supply of raw materials and equipment (Cho and Mathews 2000, 38). There was no doubt that the formation of a production network for packaging and testing ensured the solid basis of industrial upgrading by providing the necessary labor force and capital accumulation.

Take, for example, the Taiwan semiconductor industry, which has relied heavily on multinational investment in packaging and testing operations since the 1960s. With the fast-growing electronics industry offering a huge amount of market demand, the IC industry's value has increased at a rapid rate of 13.2 percent in 1986–1992 and 27.6 percent in 1993–1998 (Tung 2001, 268). In 1995, as the fourth largest IC producer, Taiwan has moved up in the global value chain of the semiconductor industry, as illustrated by the rise of IC manufacturing revenue, which is more value-added than IC packaging operations.

Table 7: Taiwan: IC-Related Revenue 1989-98
(Cho and Mathews 2000, 48)



(4) Power competition and national strategy

The semiconductor industry is not only a technology-intensive sector but also a capital-intensive sector, as well as the basis of several industries, which has always attracted the attention of governments all over the world. The rise of the Japanese semiconductor industry threatened the status of American interests, which triggered years of trade wars between the two countries. With the aim of weakening the potential capability of industry upgrading in Japan, the American government chose to cultivate a substitute to replace Japanese firms. Meanwhile, both the Korean and Taiwanese governments devoted all their efforts to nurturing their technological capabilities in this strategic industry and making it the national strategy. Benefiting from the power competition between the U.S. and Japan, Asian countries like Korea, Taiwan, and even Singapore succeeded in capturing the technology transfer from leading firms in both countries and eventually cultivated their own semiconductor production network. The development of the semiconductor industry in those countries was not just stimulated by the private sector's pursuit of high profits but also shaped by the national strategic competitions among powers.

The Korean government devoted a lot of effort to promote the semiconductor industry in its early stages, e.g., by covering part of the R&D expenses for new technology and developing an overall plan to stimulate the industry, including financial and fiscal support for R&D, production, marketing, and labor training (Byun and Ahn 1989, 646). Moreover, the role of the Taiwan government in developing its semiconductor industry was irreplaceable: the foremost role was to obtain foreign advance technology and to do domestic research through national projects; the second role was to stimulate demand through promoting firms to commercialize these advance technologies to meet market demands; another role was to build a comprehensive supporting industry as well as the competitive infrastructure to offer necessary services to the manufacturing of ICs (Liu 1993, 304–306).

The ongoing third wave of the industry transfer

In the past four decades, the IC industry has experienced striking growth and brought great economic influence: cost reductions and performance improvements made it possible for the electronics industry to evolve from mainframes to PCs in the 1990s, the internet-related industries in the 2000s, and the smartphone industry in the 2010s (SIA 2021, 11). Corresponding with these chip-enabled innovations, the first two waves of semiconductor industry transfers took place, which illustrated the correlation between the subversive industry innovations and the semiconductor industry transfer. Those chip manufacturers who captured the market demands created by the emerging electronic industry would grow up and even dominate in the next stage: Japan grasped the chance in the age of mainframes and dominated the

DRAM industry; Korea and Taiwan captured the chance in the age of PCs, then caught up with the U.S. and Japan and dominated the DRAM industry and foundries, respectively. Therefore, there is no doubt that the smartphone revolution in the 2010s could be a great chance for Chinese semiconductor firms to catch up with the leading firms and occupy more market shares than before, with the help of massive industrial policies created by the Chinese government. However, the potential industry transfer was interrupted by the U.S. and provoked the power competition between China and the U.S. much earlier than previously, which potentially made it uncertain for China to grow up into the next semiconductor production center.

1. The possibility of the rise of Chinese semiconductor industry

Due to intense competition in the semiconductor industry, Chinese firms found it more difficult than ever to obtain licensing agreements from leading companies. However, there are still plenty of chances for China to successfully undertake the semiconductor industry transfer and become one of the production centers in the world, due to its huge market demands, a production network formed by FDI and domestic firms, as well as the strong support from the government's industrial policies.

(1) Market demands

Like Taiwan in the 1990s, the electronics industry has recently become one of the leading sectors in the Chinese economy due to the cheap labor force and satisfactory investment environment created by the local government. China is a powerhouse in the electronics sector. With a nominal GDP of more than $14.7 trillion in 2020, the value of the Chinese electronics industry was nearly $350 billion, or almost 25 percent of the world assembly value in 2020 (GlobeNewswire 2021). The market demands of chips created by the electronics industry spurred the domestic development of the semiconductor industry: in 2017, China's IC production sales was $13 billion, almost 3.8 percent of the worldwide chip sales; in 2020, the Chinese IC industry reached an unexpected growth rate of 30.6% with $39.8 billion in total annual sales, which helped China capture 9 percent of global chip market in 2020, transcending Taiwan for two consecutive years and following Japan and the EU which took of market share respectively (SIA 2022).

(2) Production network

China has been devoted to developing its own semiconductor industry since 1965; however, due to its blocking economic environment, there were no possibilities for China to capture the technology diffusion and catch up with leading firms in the U.S., Taiwan, the EU, and so on. Since 1979, China has been open to foreign investment, even creating the Ministry of Electronics Industry (MEI) to regulate the FDI that poured into the electronics industry. By the mid-1990s, the world's leading firms planned to conduct or upgrade IC production operations in China, such as

Advanced Semiconductor Manufacturing Corporation (ASMC), which is the joint venture with Philips in Shanghai, and a huge high-technology park created by the Singapore government in Suzhou, where much of China's future semiconductor industry is likely to be located (Cho and Matthews 2000, 63–64). Given that Wuxi has been the "Silicon Valley" of China due to the investment of state-owned enterprises like Huajing Electronics and Jiangnan Semiconductor Devices, the Yangtze River Delta has formed the most important production network for the Chinese semiconductor industry, which has not only cultivated huge amounts of skilled labor but also provided valuable chances for the domestic firms to move up in the global value chain of the semiconductor industry.

(3) Industrial policy

Since 1956, the Chinese government has played an important role in helping to develop its own semiconductor industry for almost half a century. However, even after reform and opening up, China's strategy to use industrial policy to improve technological advances in the semiconductor industry has met with limited success in the 20th century. The reasons were various: the problem of Chinese bureaucracy, the division of power between central and local government, which impedes execution of policies across the country; the methods taken by the government, which promote and impede high-tech firms' performance; the government's corruption; the mismatch of resources to the SOEs; and the lack of ability to absorb FDI-related knowledge spillovers (VerWey 2019, 8). After entry into WTO in 2001, especially the establishment of SMIC in 2000 and starting volume production in 2002, Chinese semiconductor industry gradually grew up rapidly. Well-structured industrial policies count: In 2005, China released a National Medium- and Long-Term Science and Technology Development Plan Outline for 2006–20 (MLP) and issued subsequent related policies to support MLP, which generated the concept of IDAR: "Introducing, digesting, absorbing, and re-inventing intellectual property and technologies as a means of industrial catch-up" (VerWey 2019, 12). In 2014, Chinese government released Guidelines to Promote National Integrated Circuit Industry and Made in China 2025, which presented detailed-strategy to lead the Chinese semiconductor industry to foster technology transfer and catch up with leading firms in the world. Meanwhile, the National IC Fund was founded by the government, according to Made in China 2025, to help implement the national IC plan. Until 2019, China has completed two rounds of IC industry investment funds: Phase I raised 139 billion yuan, which ended in 2018, and Phase II collected 204.2 billion yuan ($28.9 billion) with the aim of achieving self-sufficiency in the industrial chain (The Wall Street Journal 2019). Well-designed industrial policies aim to foster technology diffusion and absorption, while Chinese semiconductor firms are granted a great chance to seize the domestic market under the requirement of "Indigenization Substitution" and accumulate enough capital to do further investment and R&D research.

2. Power competition between U.S. and China

In the context of power competition between the U.S. and China, the third wave industry transfer of semiconductors presented a complex characteristic: Reshoring semiconductor manufacturing capacity is a primary task for U.S., Meanwhile, cutting off the technology diffusion, even disengaging with Chinese economy are adopted by American government to deter the growth of Chinese semiconductor, which never showed up in the previous industry transfers.

As is illustrated above, innovations in the IC industry help stimulate more market demands and exploit new markets entirely, which will enable a great many innovative technologies, including 5G, artificial intelligence (AI), autonomous electric vehicles, and the internet of things (IoT) in the next decade (SIA 2021, 12). In other words, as the foundation of all those emerging technologies related to national security, the semiconductor industry, especially the wafer fabrication capacity, has become an essential part of national power, which could cast an essential influence on the international power structure and attract the attention of great powers in turn. With the fast growth of the Chinese electronics industry and the strong industrial policies released by the Chinese government, the U.S. government is afraid that China will gradually catch up with American firms in the semiconductor industry like other Asian countries in history. When Trump came into power in 2017, USTR initiated Section 301 investigations into China's unfair trade practices as well as its unfair and even illegal technology transfers. The semiconductor industry became the focus of power competition again; however, unlike Japan in the 1980s, China has not built dominance in any semiconductor segments compared with leading firms in developed countries, even after decades of development. Therefore, the semiconductor industry, especially the advance technologies owned by the American firms, are used to be a technology leverage to help U.S. deter Chinese firms' rise in any innovative technologies, take Chinese company Huawei for example: afraid of the leading advantages of Huawei in 5G field, the Trump administration imposed series of restrictions on Huawei by cutting off all access to US technology, especially chip technology, which made Huawei run out of chips stocks and stop producing its own chips (AP News, 2020). Later on, the Biden administration pointed out that the share of American IC manufacturing capacity has reduced from 37% 20 years ago and now reaches about 12% of global production, and U.S. semiconductor firms highly rely on external sources for IC production, especially in Asia, disclosing a supply chain risk that could definitely threaten national security (The White House 2021, 22). Moreover, the COVID-19 pandemic shows the importance for U.S. to strengthen the global semiconductor supply chain in an uncertain era, when facing the power competition between U.S. and China. Meanwhile, Congress recognized the pivotal role of the American semiconductor industry in America's future. Both the House and the Senate tried to authorize the CHIPS Act to increase domestic investment in semiconductor research, design, and manufacturing. Besides, Congress is also discussing legislation called the FABS Act that would introduce a semiconductor investment tax credit (SIA, 2022). Currently, both the government and the Congress are determined to rebuild the competitive production network in the U.S. and deter the growth of Chinese semiconductor firms by blocking the diffusion of technology.

Conclusion

The three waves of semiconductor industry transfers in history and the present are excellent examples to illustrate the relationship between technology diffusion and power transition. Latecomers generate their own technology based on imported technology, which is deemed as international technology diffusion: e.g. the American dominance in the DRAM industry in the 1970s and the 1980s was transfer to the Japanese in the 1990s, and then was passed to the Koreans in the 2000s, these evolution was corresponding with the order of entry into the industry and following with the industry transfer (Lee and Yoon 2010, 568). Production network is the nexus between technology diffusion and international power structure: technology transfer promotes the formation of the semiconductor production network in East Asia, and gradually reshapes the international power structure of production. East Asian countries succeeded in establishing the competitive production networks of the semiconductor industry in the previous two waves of technology transfer, which greatly challenged the dominance of American firms and shaped the current international power distribution in the field of the semiconductor industry. Each wave of technology transfer stirred up the power competition between the dominant country and the rising state; the most famous one was the semiconductor trade conflict between the U.S. and Japan. Nowadays, with the rapid rise of Chinese economy, its semiconductor industry showed the similar trend to catch up with the leading firms of the U.S. through the technology spillover, which arouse American worries and provoked power competition between the U.S. and China. The technology diffusion channel was blocked by the American government in order to deter the rise of the Chinese semiconductor industry as well as the potential dominance of the future technologies; meanwhile, industrial policies were released by the governments of the U.S., Japan, Korea, China, and even Europe. The third wave of technology and industry transfer will definitely be affected by technology diffusion, industrial policy and the power competition, which will cast a profound influence on the international power structure in the future.

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