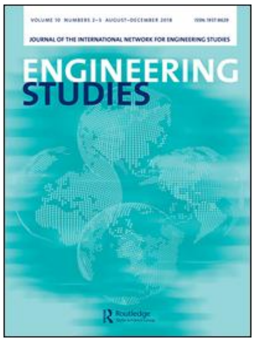

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Transfer of 'Engineer's Mind': Kim Choong-Ki and the Semiconductor Industry in South Korea

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ABSTRACT
By the mid-2000s, South Korea had become a dominant power in semiconductors, and by the mid-2010s, its worldwide market share of memory had climbed to over 60%. Many scholars have endeavored to discover the secret of the South Korean success but have usually emphasized the roles and contributions of the South Korean government and individual companies in the development of semiconductors, almost totally neglecting those of the South Korean academy. This article analyzes how the South Korean academy contributed to the development and success of the semiconductor industry by examining the life and work of Kim Choong-Ki of Korea Advanced Institute of Science and Technology (KAIST). Beginning in 1975, Kim trained the first two generations of semiconductor engineers at KAIST, most of whom became the field's leading figures in academia, at research institutes, and especially in industry. This study is not a biography of Kim but a critical analysis of how a university professor, not an entrepreneur, became the 'godfather' of the semiconductor industry in South Korea. I argue that this was only possible within South Korea's unique triangular relationship among government, industry, and academia during the last quarter of the twentieth century.

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By the mid-2000s, South Korea had become a dominant power in semiconductors, and by the mid-2010s, its worldwide market share of memory had climbed to over 60%. Samsung Electronics, South Korea's flagship electronics company, became the number-one semiconductor manufacturer in the world (in revenue) in 2017, and another South Korean semiconductor company, SK Hynix, was number three.[1] In 2018, semiconductors even made up 21% of South Korea's entire exports and 6.7% of its GDP.[2] This is a truly amazing achievement for a nation that started assembling radio sets only in 1959 and began to manufacture outdated memory chips only in the mid-1980s.

Many books and articles have been published to explain how South Korea's semiconductor industry accomplished such brilliant success within such a short period.[3] These works usually emphasize the roles and contributions of the South Korean government and individual companies but almost completely neglect those of the South Korean academy. Most authors of these works, whether economic analysts or professors of business management,

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Figure 1. Kim Choong-Ki at the award ceremony for the Hoam Prize in 1993. In the lower photo, Lee Keun Hee, Chairman of the Samsung Conglomerate, is second from the left and Kim Choong-Ki is fourth (Courtesy of Hae-Ja Chang Kim).

consider US-trained South Korean engineers in the 1980s and 1990s to have been convenient and important conduits through which state-of-the-art knowledge and technology flowed smoothly from the US to South Korea. Almost no studies, however, clearly explain *what* was actually brought from the US to South Korea, or *how* that transferred technology and knowledge were successfully disseminated to and implemented in the South Korean semiconductor industry. R&D and manufacturing semiconductors require not only a handful of highly educated and experienced US-trained star engineers but also dozens or even hundreds of rank-and-file engineers: Who supplied them?

This article analyzes how the South Korean academy contributed to the development and success of the country's semiconductor industry by examining the life and work of Kim Choong-Ki of Korea Advanced Institute of Science and Technology (KAIST). Ever since receiving the coveted Ho-Am Prize for Science and Engineering in 1993 (Figure 1) for his contributions to 'the research of semiconductor devices and integrated circuits for over two decades' and for 'building a solid foundation for Korea's semiconductor industry', Kim has been widely called 'the godfather of the semiconductor in Korea'.[4] Kim's former students at KAIST have become leading figures in academia, research institutes, and particularly in industry: some of them have reached the top management positions at Samsung Electronics, LG Electronics, and Hynix. By analyzing his role as a mentor in South Korean semiconductor circles during the last quarter of the twentieth century, this article focuses on the following question: How can we position Kim Choong-Ki in South Korea's unique triangular relationship among government, industry, and academia?

A unique start: Kim Choong-Ki's early years

Kim Choong-Ki was born in Seoul on 1 October 1942. His father, Kim Byeong-Woon, was a famous textile engineer and a major influence on Choong-Ki's future career as an engineer. After graduating from Keijo (or Kyungseong) Technical Higher School in Seoul in 1935, Kim Byeong-Woon was hired by Kyungseong Bangjik (better known as Kyungbang), the largest Korean textile company during the Japanese colonial period, and quickly rose to be the most respected engineer in the company. When Korea was liberated from Japanese rule on August 15, 1945, Kim Byeong-Woon was promoted to chief manager of the main factory in Seoul at the relatively young age of 33. During and after the Korean War, he was responsible for rebuilding the factory and assembly lines from the ashes and ruins.[5] Unlike other Korean engineers of his generation, Kim Byeong-Woon did not crave higher management positions or academic jobs but remained as a hands-on engineer throughout his entire life. Kim Choong-Ki and his brother Joon-Ki would become his most faithful disciples with their contributions to the semiconductor and computer industry in the last quarter of the twentieth century.[6]

Kim Choong-Ki was a typical South Korean model student at Deoksu Elementary School, Kyunggi Middle and High Schools, and Seoul National University (SNU): he was always one of the top students in his class and was obedient and silent at school, concealing his intellectual curiosity perfectly in front of teachers and friends. Although his relatives pressed him to study textile engineering, he chose to enter the Department of Electrical Engineering at SNU. Yet he was not satisfied with the education there, which emphasized 'the designs and theories of the transformer, generator, power transmission, motor, etc.', and instead attended many courses offered by the Department of Applied Physics.[7]

Nonetheless, when Kim Wan-Hee of Columbia University asked the Department of Electrical Engineering at SNU to recommend its brightest student, the department selected Kim Choong-Ki, who then went to Columbia for advanced study in 1965. After passing the qualifying examinations, he chose as his advisor Edward S. Yang, a specialist in transistor theory, while becoming a specialist in semiconductors himself. His doctoral dissertation, 'Current Conduction in Junction-Gate Field-Effect', suggests a plausible theory to explain complicated experimental data: 'The theory presented in this dissertation explains the important features of the experimentally observed steady-state drain characteristics by clarifying the contribution of the various physical mechanisms to the current conduction'.[8] After receiving his doctorate from Columbia, Kim Choong-Ki was hired by the Research and Development Laboratory of Fairchild Semiconductor in Palo Alto, California, in the summer of 1970.

Figure 2. Kim Choong-Ki at the Research and Development Laboratory of Fairchild Camera and Instrument in Palo Alto, California. His experience at Fairchild between 1970 and 1974 greatly influenced forming his engineer's mind (Courtesy of Hae-Ja Chang Kim).

It was during his five years at Fairchild that Kim Choong-Ki was transformed from a shy model student into an idiosyncratic, self-assured, and communicative semiconductor engineer (Figure 2). His engineering potential, which had lain dormant during his schooling in South Korea, began to bud at Columbia and blossomed at Fairchild. He had learned semiconductor theory at Columbia, but it was at Fairchild that he learned the practices needed to make theories actually work.

Two things at Fairchild influenced him deeply. The first was that he encountered state-of-the-art Charge-Coupled Device (CCD) technology there. Just the year before, in 1969, Willard S. Boyle and George E. Smith of Bell Laboratory had proposed the new idea of the CCD, which eventually brought them the Nobel Prize in Physics in 2009.[9] A CCD is

> an integrated circuit that captures and stores light and displays it by turning it into an electrical charge. Each CCD chip is composed of an array of Metal–Oxide-Semiconductor (MOS) capacitors, and each capacitor is a pixel. When electrical charges are applied to the CCD's top plates, they can be stored within the chip's structure. Then, digital pulses applied to the top plates can shift these charges among the pixels, creating a picture representing charged pixels.[10]

CCD image sensors would soon be widely used in professional, medical, and scientific applications, such as consumer and professional digital cameras.

Kim Choong-Ki's years at Fairchild were devoted to this emerging field of technology. Fairchild was a pioneer in CCD technology, along with RCA, Texas Instruments, and Kodak, and it asked Kim to work on this field when he arrived at the Palo Alto research center.[11] Kim and his colleagues at Fairchild developed a new kind of CCD – buried-channel charge-coupled devices – which 'offer many advantages over [original] surface channel devices at the expense of only one additional step in the fabrication process'.[12] This new method of making CCDs led them to develop a high-performance CCD area image sensor that greatly improved image detection in low light, and also to create the world's first CCD linear image sensor.[13] Later, Kim remembered that 'about a half hour before closing the office, people came to my office to ask something about CCD. Soon they began to call me

"Professor CCD"'.[14] In short, Kim was one of few South Koreans who had substantial hands-on experience and state-of-the-art theoretical knowledge in semiconductors in the early 1970s.

The second thing at Fairchild that fundamentally changed Kim's attitude toward engineering was the company culture. This can be divided into two. First, it was at Fairchild that Kim realized that book learning alone was not sufficient for practicing engineering in the real world. When he was forced to attend a lecture course at the company campus, he quickly recognized that it was quite different from how he had studied at Columbia:

> though the course used the exactly same textbook that I had studied at Columbia. Each chapter was taught by a different lecturer who had worked on that specific field for more than ten years. Lecturers taught us what they had actually experienced rather than what was written in the textbook. I really learned a lot from this course.[15]

He also began to read internal technical reports and memos that he could find at the company library, and 'really learned something new from these informal reports and memos that I had never learned at the university'. He later brought many of them to South Korea and taught them at KAIST.

The other lesson was how to communicate, manage, and lead other engineers in the company. Kim had always been quiet and introverted, as was expected of a typical South Korean model student. However, Fairchild's company culture demanded that he adopt very different ways to survive and thrive there. The course that he had to attend to become a manager changed his previous manner completely.[16] He remembered that the instructor and fellow classmates advised him to 'unmask' and express his ideas to others for better communication. He accepted the advice and determined to change himself:

> From then on, I intentionally became much more conversant, telling jokes or talking about my interests to anyone around me. After one or two months passed, I found that my popularity began to rise. People came to my office about a half hour before the closing for just chatting or asking me about CCD.

The converted Kim Choong-Ki would become the most 'loud-speaking' professor at KAIST, one whose absence made the whole campus seemed quiet.[17]

Although Kim Choong-Ki rose quickly within the company hierarchy, in 1974 he began to seriously consider returning to South Korea. There were three reasons for this change of mind. First of all, his beloved father had died in December 1972. His two elder sisters and his younger brother were all in the United States and seemed to have settled down there. As the oldest son, he felt a heavy responsibility to care for his widowed mother in South Korea.[18] Second, the racial discrimination in the United States hurt his pride. In the early 1970s racial discrimination was not an accident but a norm. Kim remembers that some Caucasian colleagues at Fairchild openly discriminated against him.[19] Third, he found an ideal place in South Korea where he could train real engineers – KAIST.

Kim Choong-Ki at KAIST

In May 1961, a military junta led by Major General Park Chung Hee staged a coup and ushered in a twenty-year program of modernization. Under Park's strong leadership and with the support of US-trained technocrats, South Korean industrialization and its economic development proceeded rapidly. In 1966 Park established a new research institute, Korea Institute of Science and Technology (KIST), which would become 'the window through which the transfer of foreign technology to domestic industry can be made'.[20] Park and his economic advisors, however, soon encountered a serious obstacle: a lack of well-trained engineers and applied scientists who could work in South Korean industry or government research institutes. There were two possible solutions: to transform existing engineering colleges so that they could produce the necessary manpower, or to establish a new institute for that specific purpose. Park chose the latter course.

In 1971 Korea Advanced Institute of Science (KAIS) was established with financial support from the United States Agency for International Development (USAID).[21] In 1981 'Technology' was added to its name, making the acronym KAIST (used hereafter). Frederick E. Terman, longtime provost of Stanford University and often called 'the Father of Silicon Valley', was invited to draw up the blueprint of this new institute. In the resulting *Survey Report on the Establishment of Korea Advanced Institute of Science*, Terman made it very clear that this new graduate-only institute aimed to 'satisfy the needs of Korean industry and Korean industrial establishments for highly trained and innovative specialists, rather than to add to the world's store of basic knowledge'.[22] A few selective fields – mechanical engineering, chemical engineering and applied chemistry, electrical engineering, industrial engineering, material science, and biological science and engineering – were chosen to support the government's Third and Fourth Five-Year Economic Development Plans. Close cooperation with Korean industry and government research institutes was strongly encouraged. In short, KAIST intended to 'win the South Korean market, not win the Nobel Prize'.

With its special emphasis on practice, KAIST was the perfect place for Kim Choong-Ki to begin training the next generation of semiconductor engineers. When he was hired there in 1975, Kim was the fourth professor in the Department of Electrical Engineering, following Na Jung-Woong (1971), Park Song-Bai (1973), and Kim Jae-Kyun (1973).[23] Park Song-Bai, head of the department, gave Kim 100 million KRW (roughly $206,000 at that time), which had been reserved for a semiconductor specialist, to build a clean room – the essential facility for semiconductor teaching and research. Kim's semiconductor laboratory soon attracted many talented and ambitious master's and doctoral candidates. As electronics became one of the primary target areas for the nation's economic development from the 1970s on, his laboratory continuously received generous funding not only from several government agencies but also from the industry.

The primary reason for the popularity of Kim Choong-Ki's laboratory was quite obvious: the semiconductor. The importance of semiconductors had been recognized by South Korean government and industry since the beginning of the 1970s. Companies such as Samsung Electronics, Gold Star (the future LG Electronics), and Daewoo Electronics needed a large number of semiconductors to manufacture their radios, TV sets, desk calculators, and electronic watches, and depended heavily on Japanese semiconductor manufacturers like Sony, Toshiba, NEC, and Sharp. Until the end of the 1970s, South Korean government and industry's efforts to develop semiconductors produced no significant results, largely because of a great lack of specialists.[24]

Unfortunately, few South Korean universities paid any serious attention to training semiconductor engineers during the 1970s. The Department of Electronic Engineering at SNU, for example, was still dominated by old subjects, such as communication or circuit theory.[25] The first professor there to focus on semiconductors, Min Hong-Sik, came to SNU in 1976, but did not receive the support Kim Choong-Ki had received at KAIST to install the facilities needed for research and education. Nonetheless, his lectures on semiconductors fascinated an undergraduate student, Kim Ki-Nam, who decided to major in semiconductors and then went to KAIST for graduate study.[26] Whereas KAIST possessed at least four professors of semiconductor engineering by 1985, including Kim Choong-Ki's own student, Kyung Chong-Min, at SNU Min Hong-Sik remained the only teacher on semiconductors until 1988, when Park Yeong-Joon was hired. SNU opened a new building dedicated to semiconductor research and education in 1985, and began to recruit more semiconductor specialists from the late 1980s on. It was only from the early 1990s onward that SNU emerged as a serious challenger to KAIST in semiconductors.

Kim Choong-Ki's laboratory at KAIST was therefore almost the sole semiconductor training ground in South Korea from 1975 to 1990.[27] Between 1975 and 1981, his first group of master's candidates worked primarily on the design and fabrication of semiconductor devices.[28] Most of the topics of these master's theses were not cutting edge by global standards, but they were very advanced ones in South Korean terms. In other words, Kim was training his students to meet the *future* rather than the present needs of the South Korean market. Rim Hyung-Gyu, who later became head of the Samsung Advanced Institute of Technology, remembered that 'When I returned to the company with my master's degree [under Kim Choong-Ki], I found myself the top specialist in semiconductors within the company'.[29] Many of these first KAIST graduates became pioneers in both the semiconductor industry and the academy: Kwon Oh-Hyun, for example, became Vice-Chairman and CEO of Samsung Electronics (2012–2018), and other students played similar critical roles in developing and manufacturing semiconductors at LG and Hynix.

Although the primary goal and function of Kim Choong-Ki's laboratory was to train semiconductor specialists, the lab actually led South Korean semiconductor research between 1975 and 1990, when most universities and companies didn't have their own research facilities. During these fifteen years, Kim and his students did research on the design of MOS integrated circuits, oxidation process of silicon, design of integrated injection logic, CCD, ROM, and the rapid thermal process.[30] They published their results in both international and domestic journals, including fourteen papers in prestigious Institute of Electrical and Electronics Engineers (IEEE) journals. One of Kim's students, Suh Kwang-Seok, became the first Korean to publish his own research, carried out in South Korea, in such a prestigious journal, *IEEE Transactions on Electron Devices*. Another, Kyung Chong-Min, was the first Korean to read results from his doctoral dissertation at an international conference, the 1981 Custom Integrated Circuit Conference.[31] In 1984, Oh Choon-Sik and Koh Yo-Hwan became the first Koreans to present the results of research carried out in South Korea at the International Electron Devices Meeting (IEDM), the most prestigious meeting on semiconductor devices.[32] For the South Korean semiconductor industry, Kim and his students developed various processing techniques for the rapid thermal process, which 'constitutes an essential part of high density memory products beyond 16M DRAM'.[33] All these research activities, 'despite poor conditions for experiments in South Korea', were quite impressive in the 1980s.[34]

The popularity of Kim's laboratory within KAIST, and of its graduates within the South Korean semiconductor industry, increased rapidly during the 1980s, when not only Samsung but also Gold Star (later LG) and Hyundai Electronics (better known as Hynix) entered the semiconductor field. The supply of semiconductor specialists, however, remained very limited: Kim and his former students' laboratories at KAIST and Kyungpook University were the main supply lines during the 1980s. Kim's students with master's or doctoral degrees were sought after by South Korean industry because they had hands-on experience in producing various kinds of semiconductor devices: about three-fourths of his master's students went into either industry (Samsung, Hynix, LG, and others) or government research institutes (Electronics and Telecommunication Research Institute – hereafter ETRI – and others) to continue their semiconductor work, with only about one-fourth remaining in academia to teach about semiconductors.[35] Moreover, Kim encouraged some students to work in totally new fields, such as Thin-Film Transistor (TFT) or Liquid Crystal Display (LCD), for their master's or doctoral degrees, and many became leading figures in those areas in the 1990s and 2000s. Kim Nam-Deog, who wrote his 1986 master's thesis on the fabrication of hydrogenated amorphous silicon thin-film transistors for flat panel display, remembered that he had not been confident about his subject in the beginning and had envied other graduate students working on memory. He became a leader in the development of LCD at Samsung beginning in the 1990s.[36]

It was not simply the popular subject of semiconductors or KAIST's virtual monopoly on training in the field that made Kim Choong-Ki a mentor without peer in South Korean semiconductor circles. In addition, it was his unique training, his unusual attitude and down-to-earth words, and his idea of engineering. These at first puzzled his students, then impressed and influenced them profoundly, and finally changed their view of engineering permanently. He demanded that each student use his or her hands as well as 'something malleable within the hard nut on your neck' (i.e. 'your brain within the skull on your neck') to become a competent semiconductor engineer.[37] Kim made his students learn and understand these lessons through practice, as clearly indicated in excerpts from the collected memoir of his former students, *Uri Kim Choong-Ki Seonsaengnim* (Our Teacher, Kim Choong-Ki):[38]

> I still clearly remember those years between 1975 and 1981 when I worked with my fellow students to install necessary equipment at the laboratory. Since Professor Kim emphasized the importance of practice and the money was not enough, we had to make and repair all the equipment by ourselves. Through these unprecedented lessons, he provided South Korean industry and higher education with a proper model of engineering education. Kyung Chong-Min

> When I first entered his laboratory, I had no clear idea of engineering. He repeatedly told us that 'Fast decisions, though wrong, are better than slow ones' or 'Be prepared to encounter the worst'. These lessons still influence me as basic principles. Kwon Oh-Hyun

> When I first came to Professor Kim's laboratory, I expected to learn something about the famous CCD. However, he did not say anything about it but ordered me to clean the empty room every day, emphasizing that the semiconductor laboratory must be clean. . . . To upgrade the pipelines and DI water system in the laboratory, I often went to Euljiro market to purchase necessary parts. My colleagues then gave me the nickname 'Pipe Park'. Park Joo-Sung

> My laboratory room decided to purchase an air-conditioner, and the discussion started. Professor Kim led the discussion to calculate the proper capacity of the air-conditioner based on the size of the room and the quantities of input and output air. People usually tell the seller the size of the room when they order it, but he didn't. That taught me a lot. . . . Thanks to this lesson, I often try modeling to deduce the results whenever I encounter similar issues. Lee Yoon-Tae

> His famous buttocks theory is that 'If you just repeat others' ideas, you will never overcome them but just follow their buttocks'. Once I was struggling with the results of simulations. He said to me, 'Did you make it? Make it by yourself! Then we will start discussions'. So, I designed and constructed the circuit and carried out measurements. I then realized why he asked me to make it. First of all, I loved the circuit that I had constructed. I paid much more attention to whether or not that circuit worked properly: when it didn't work, I began to analyze the cause of its failure . . . I learned that what is so obvious in theory in a book or an article may not be so obvious in reality, that something ideal is in fact only 'ideal', that I must consider every contingency, and that I must be open to every possibility.
> Oh Hyung-Seok

The engineer's mind that Kim wanted to cultivate in his students was a balanced attitude between theory and practice. Since most South Korean engineering students in the 1970s and 1980s generally regarded engineering as another book-learning discipline, his equal emphasis on practice must have been quite a shock to them: many anecdotes about Kim are therefore related to hands-on practice. This emphasis on practice was not confined to Kim's laboratory but was also widely employed by other professors at KAIST during the period, especially those in the Department of Electrical Engineering. However, it was Kim Choong-Ki who epitomized this approach through his inimitable words and unflagging persistence over more than three decades.

Another important factor that made Kim popular and influential was that he was always willing to cooperate with anyone and that his laboratory was open to outsiders. Kim liked to work with younger professors in the Department of Electrical Engineering and often shared the laboratory space with them. He also liked to visit the laboratories of other departments and talk with professors and students there to get new ideas and perspectives. To encourage his own students to do the same thing, he organized a monthly dinner meeting and invited professors or advanced doctoral candidates from other laboratories and departments to meet his students. An excerpt from Kim Jun-Ho's piece in the collected memoir illustrates this point:

> My recent research subject is Bio-MEMS (Biomedical Micro-Electro-Mechanical Systems), which requires interdisciplinary research with biology or chemistry groups. Although I have only studied electronics, I can carry out this research without much difficulty, perhaps owing to Professor Kim's training. If I had not received his training that emphasized interdisciplinary cooperation, I would have a lot of trouble.[39]

Between 1975 and 2010, Kim produced 72 master's and 39 doctoral graduates.[40] At the same time, scores of others were directly or indirectly influenced by him through his openness. An example is Chin Dae-Jae, who successfully developed 16M DRAM at Samsung in the early 1990s, and then served as Minister of Information and Technology (2003–2006). Although he was not Kim's own student at KAIST, Chin's autobiography acknowledges his debt to Kim as follows:

> In the early 1970s, South Korea was just a beginner in the semiconductor field. There was no systematic education on the subject so that we had to study it by ourselves. In late 1974 [*sic*], a South Korean who had studied semiconductors in the US returned, and the situation began to change. That person was Professor Kim Choong-Ki of KAIS, who is often called the 'godfather' of semiconductors in South Korea. For those like me who wanted to study semiconductors, he was a savior . . . So my colleagues and I at Seoul National University actively used this opportunity, inviting him to organize seminars or to have discussions. There was an intense spirit of competition between Seoul National University and KAIS in those years. Since I often went

> to KAIS to study the semiconductor with Professor Kim, I soon became a ‘problem’ student at Seoul National University.[41]

Kim not only helped those who studied semiconductors in the academy but also enthusiastically assisted those who worked in industry and government research laboratories. For example, he served as director of research and development at the Korea Institute of Electronics Technology (KIET) at Gumi in 1982–1983, when the institute successfully developed both 32 and 64 K ROM under his directorship.[42] He was also eager to spread recent knowledge and know-how on semiconductors through KAIST’s industry-academy cooperation workshop programs during the 1980s. These workshops were so popular and successful that Samsung, LG, and Hynix decided to set up their own special, tailored educational programs at KAIST to train necessary semiconductor manpower in the 1990s. This kind of close cooperation with the semiconductor industry helped Kim build and operate the Integrated Circuit Laboratory, Semiconductor Workshop for Young Engineers, Center for High-Performance Integrated System (CHIPS), Center for Electro-Optics, and others during the 1980s and 1990s, most of which were funded by industry.[43]

In the spring of 1994, Kim Choong-Ki was appointed the director of KAIST’s newly created office of overall planning, and then served as vice president between 1995 and 1998. He therefore paid more attention to the management and future planning of KAIST, and to the directorships of several semiconductor institutes at KAIST, than to training semiconductor specialists in his laboratory.[44] Some younger professors in his department lamented the fact that Kim, then in his early fifties, was not continuing in his role as a mentor as much as before. Kim, however, thought that his mission as a pioneering teacher in semiconductors was almost complete, since by the early 1990s there were rapidly increasing number of young semiconductor specialists not only at KAIST but also at other universities.

As a high-ranking administrator responsible for all of KAIST’s research and education, Kim paid special attention to the future direction of research and education as well as to strengthening the undergraduate program. In an interview held in 1997, he outlined the future goal of KAIST’s education as follows:

> Education in science and engineering in Korea was like teaching [students] how to read maps, to find out where you want to go . . . And who made the maps? Advanced countries. We now have to change our educational policy and teach our students how to draw the maps.[45]

Kim soon realized that it is much more difficult to change the educational policy and environment than to train more than a hundred of semiconductor specialists. Strengthening the undergraduate program also encountered serious obstacles because in the 1990s most KAIST professors considered this program to be a waste of their valuable research time. These two ambitious plans therefore did not achieve much during his tenure as vice president but only began to slowly be realized in the twenty-first century.

In the spring of 2007, Kim Choong-Ki was elected one of KAIST’s first three ‘Distinguished Professors’, a position that virtually abolishes the compulsory retirement age of 65 and provides the elected professors with a special research fund.[46] At a ceremony in his honor on 25 February 2008, he was asked to give a short speech summarizing his life and work.[47] To everyone’s surprise, he spent almost half the time recalling how deeply his father had influenced his life and career. Kim Choong-Ki was doubly lucky to successfully absorb the qualities of a true engineer's mind not only from the United States but also from his father – a very rare occurrence in modern South Korea.

Kim was also something of an exception on the international stage. It is important to remember that the South Korean government was not alone in making microelectronics and semiconductor manufacturing in important part of its strategy for rapid industrialization. Particularly in East and Southeast Asia, this industry was prioritized: in Japan, Hong Kong, Singapore, Malaysia, and to some extent the Philippines and Thailand. Taiwan offers the closest parallel to South Korea's path, so it is helpful to compare Kim with two Taiwanese semiconductor specialists, Morris Chang and Simon Min Sze, who played similarly facilitating roles in the growth of their country's microelectronics and semiconductor industry. In that way we can see what was unique not only about Kim, but also about the South Korean path to building its semiconductor industry.

Morris Chang, the 'Silicon Godfather' in Taiwan, was trained at MIT and Stanford University, and worked at Texas Instruments for twenty-five years.[48] In 1985 he moved to Taiwan, where he became the head of the Industrial Technology Research Institute, and then established the Taiwan Semiconductor Manufacturing Company (TSMC), which soon emerged as one of the major semiconductor companies in the world.[49] Simon Sze was also thoroughly trained in the United States: he studied at the University of Washington and Stanford University, and worked at the Bell Laboratory for twenty-seven years.[50] At Bell Labs, he made some important discoveries, including the floating-gate transistor with Dawon Kahng, and published several important textbooks on the field. He returned to Taiwan in 1990 to become an influential professor at the National Chiao Tung University, where he trained many semiconductor specialists for Taiwanese industry.

Kim Choong-Ki and these two Taiwanese semiconductor specialists shared American education and company experience, but differ in *how* they influenced and contributed to the development of the semiconductor industries in their countries. Kim and Sze's principal role was that of a teacher who trained semiconductor specialists at universities in their home countries. They were quite dissimilar, however, in terms of *when* they returned home and *what* they taught the next generations. Kim returned to South Korea in 1975, at the age of 33, when the South Korean semiconductor industry had barely started, and therefore had to teach his students *how* to think with an engineer's mind so that they could go on to develop semiconductors and survive in the industry. Sze, in contrast, returned Taiwan in 1990, at the age of 54, when the Taiwanese semiconductor industry was already growing; as a world-renowned specialist in semiconductors, his role was the more conventional one of writing textbooks, doing research, and consulting, which was enough to stimulate the Taiwanese semiconductor community. Chang's role was quite different from that of the other two. He suggested the future direction of the Taiwanese semiconductor industry – foundry work – and became an entrepreneur himself to realize his idea. Perhaps Chang, as an engineer-turned-entrepreneur, seems the most likely of the three to have become an influential leader in a high-tech industry like semiconductors: Gordon E. Moore and Robert Noyce's establishment of Intel in 1968 may be a good earlier example of such a trajectory.

How is it, then, that Kim Choong-Ki, a university professor without the brilliant achievements of Simon Sze or the entrepreneurial vision of Morris Chang, became the godfather of the semiconductor in South Korea?

How do we position Kim Choong-Ki in the triangular relation of government-industry-academy?

To position Kim Choong-Ki in the development of semiconductors in South Korea and understand how he became the godfather of the semiconductor industry, it is essential to understand the unique framework of the collaboration among the South Korean government, industry, and academia during the last quarter of the twentieth century. The triangular relationship among government, industry, and the academy for the development of semiconductors differs by country. In the United States, government-supported R&D (particularly from the military and space program) provided the infant semiconductor industry with some important stimulus until the early 1970s, but the initiative then moved to industry and the role of academia also increased. In Japan, industry was the major player from the beginning of the development of semiconductors, while both government and academia were largely consigned to supporting the industry.[51] The severe competition between the American and Japanese semiconductor industries during the 1980s made each government ask its industry to form a consortium for the development of VLSI (Very Large Scale Integration) semiconductors, but this was a rare and one-time intervention.[52] In Taiwan, South Korea's rival in semiconductors, the government's initiative and dominant role quickly passed to industry, especially after the establishment of TSMC in 1987, and the academy made few contributions to the process.[53]

In South Korea, the initiative and the power balance among the three actors changed dramatically between 1965 and 2000 (see Figure 3). In the early phase between the mid-1960s and the mid-1980s, the South Korean government was the true prime mover in semiconductor development by setting specific goals, establishing related research institutes, and pushing both industry and academia, which were less enthusiastic or even passive in comparison. From 1983 on, however, it was industry that led the rapid and successful development of semiconductors, and the academy's role and contribution also steadily rose, while the government's previously over-dominant influence declined rapidly.

At the outset, it was the South Korean government, not the academy or industry, that seriously considered semiconductors as a promising future area for the South Korean economy. In 1967 the South Korean government invited Kim Wan Hee to draft a plan for the development of the electronics industry in South Korea.[54] Following Kim's strong advice, President Park ordered preparation of the necessary laws and detailed plans, which were enacted as 'The Electronics Industry Promotion Act (1968)' and 'The Eight-Year Plan for the Electronics Industry Promotion (1969)'. On 12 January 1973, President Park declared that his government would focus both the Third Five-Year Economic Development Plan (1972–1976) and the following Fourth Plan (1977–1981) on heavy and chemical industry, which included iron/steel, non-ferrous metals, chemicals, machinery, shipbuilding, and electronics. The oil crisis in the fall of 1973 then forced the South Korean government to pay more attention to the electronics industry, which consumed relatively less energy than other heavy industry.

As a result, the final version of the Fourth Five-Year Economic Development Plan promoted electronics from a minor field under machinery in the Third Economic Plan to the second most important field under heavy industry, and gave special emphasis to the development of semiconductors and computers.[55] A special institute, Korea Institute of Electronics Technology (KIET), was established to accelerate the government's efforts in

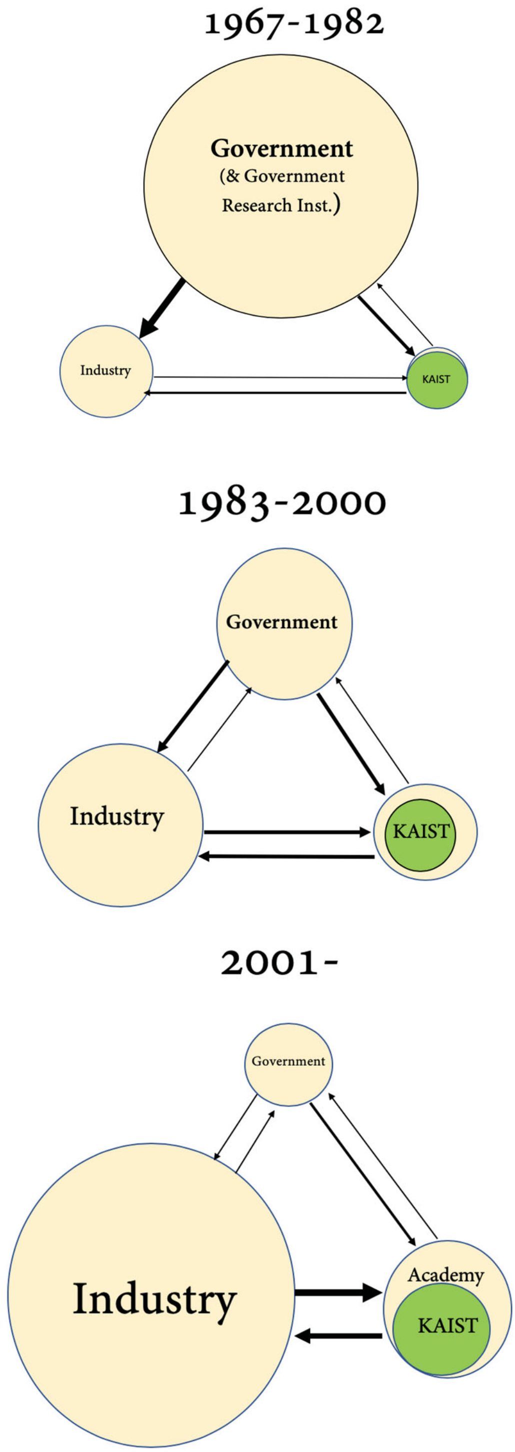

Figure 3. Change over time in the triangular relationship among government, industry, and the academy in South Korea.

1976. In September of the same year, a special report, 'Electronics Promotion Plan: Semiconductor and Computer Industry', was issued: it warned that 'if we don't start semiconductor right now, we will meet serious difficulties soon'.[56] Park's government not only forced industry to pay more attention to semiconductors but offered industry special low-interest funding and tax benefits, such as exemption from import taxes when importing necessary facilities for producing semiconductors.[57]

The South Korean government's initiative in the development of semiconductors continued in the early 1980s. The new military government, which seized power by a series of coups in 1979–1980, issued a 'Basic Plan for the Promotion of Electronics' on 14 January 1981, in which the semiconductor industry was identified as 'the core industry' to promote.[58] The government would offer special funding for the research, development, and manufacturing of selected items, such as digital integrated circuits and small computers: in the case of digital integrated circuits, the list indicated 'I-chip Micro-computer, Microprocessor (design of circuit), Memory (wafer process technology)' as the top three goals. With these detailed plans, the government began to press the big three – Samsung, Gold Star (the future LG Electronics), and Hyundai – 'to make serious commitments' to semiconductors.[59] And it worked. In his recent memoir, one of the coup leaders, President Chun Doo-Hwan (1980–1988) proudly recalls his strong support of and critical role in semiconductor development during his tenure.[60] When Samsung, Gold Star, and Hyundai hesitated about developing 4M DRAM in 1986 because of its astronomical cost, he summoned the heads of the three conglomerates to the presidential residence and insisted that they work together. They had no choice but to do so, along with the newly established ETRI (the former KIET), and succeeded in developing 4M DRAM about fifteen days before Chun's retirement in February 1988.[61]

It is interesting to examine the contribution of government research institutes to the development of semiconductors. Ever since KIST was established in 1966, KIST and its spin-off institutes had played very important roles in many fields, such as steel, automobiles, shipbuilding, electronics, and telecommunications.[62] The standard process during the 1960s, 1970s, and even 1980s was that a specific government research institute developed the necessary technology and then transferred it to the corresponding industry. However, KIST, KIET, and later ETRI had done relatively little in the development of semiconductors: their research on semiconductors was intermittent, and the few valuable experiences acquired were not accumulated properly.[63] The development of 4M DRAM in the mid-1980s was therefore the first major – and also the last – achievement in semiconductors by the government research institutes. After the mid-1980s, the major South Korean semiconductor companies wanted to develop the necessary technology themselves, and declined the government's offer to collaborate with ETRI in developing 64M and 256M DRAMs, as had been done for 4M DRAM.[64] ETRI's own history indicates that its major contribution after its 1986 inception was not in semiconductors but in telecommunications, such as in the developments of Time Division Exchange (TDX) technology and Code Division Multiple Access (CDMA) technology.[65]

In contrast to the South Korean government's early efforts to develop semiconductors, the country's electronics industry had not been seriously interested in semiconductors until the mid-1970s. The origin of the South Korean electronics industry was humble, and the first serious company, Gold Star, only appeared in 1958.[66] During the 1960s more electronics companies were founded, and foreign companies such as Fairchild, Signetics, Motorola, IBM, Control Data, and AMC built their own production lines in South Korea to make transistors and various semiconductors for export.[67] The establishment of Samsung Electronics in 1969 not only stimulated existing companies such as Gold Star but also prompted other conglomerates such as Hyundai and Daewoo to enter the electronics field, which contributed greatly to the rapid development of electronics.[68]

With pressure from the government and the rapidly increasing demand for semiconductors in the manufacture of radios, televisions, microwaves, and watches, the South Korean electronics industry began to develop semiconductors from the mid-1970s on. Gold Star, Anam Semiconductor, and Samsung Electronics began to produce transistors and a few integrated chips from the mid-1970s, but all electronics companies still imported more advanced semiconductors from Japan and other countries. The establishment of Korea Semiconductor and its immediate failure in 1974 indicated both the high demand for advanced semiconductors and the unprepared environment in South Korea in the mid-1970s. Established by Kang Ki-Dong, a Korean American semiconductor engineer, Korea Semiconductor succeeded in producing the first Large Scale Integration (LSI) chip in South Korea, but faced financial difficulties within a year.[69] Lee Kun-Hee, the future head of the Samsung conglomerate, privately bought 50% of the company's stock, paving the way for its future success. In 1977 Samsung bought the remaining stock and changed the company's name to Samsung Semiconductor, though this new business didn't produce any significant results until 1983.[70]

This mediocre situation changed dramatically in the early 1980s, when the new military government strongly pressed major electronics companies to develop and manufacture more advanced, VLSI-level semiconductors. Lee Byung-Chul (founder of the Samsung conglomerate) carefully studied the market and necessary technology for a year, and finally made the decision to enter the memory business (DRAM) in February 1983.[71] With technical assistance from Micron Technology (US) and Sharp (Japan), Samsung's two research teams, one in the suburbs of Seoul and the other in Silicon Valley, each succeeded in developing 64 K DRAM by November of that year. The Samsung conglomerate decided to invest about $133 million – an astronomical amount at that time, when South Korea's total annual exports were just over $10 billion – to build a production line of 64 K DRAM. Samsung also succeeded in developing 256 K DRAM by the end of 1984, 1M DRAM by July 1986, and 4M DRAM (with Gold Star and Hyundai) by February 1988.[72] Steep drops in the price of DRAMs – for example, the price of 64 K DRAM dropped from $3.50 in mid-1984 to $0.30 in mid-1985 – led the Samsung conglomerate to the edge of bankruptcy, but the personal computer boom revived the demand for 256 K DRAM and erased all accumulated deficit by 1988. Gold Star and Hyundai, Samsung's domestic rivals, followed Samsung's model of developing and manufacturing DRAM and other VLSI semiconductors from the mid-1980s on. By the time Samsung Electronics announced the development of 64M DRAM for the first time in the world in September 1992, the South Korean semiconductor industry was no longer either a 'copy-cat' or a 'fast follower' but the dominant player in the world market.

What, then, did the academy contribute to the development of semiconductors? Most previous scholarly works, memoirs, and company histories have emphasized both government and industry's contributions but ignored the role of the academy.[73] Nevertheless, it was the academy that provided both government research institutes and the electronics industry with the manpower required to carry out semiconductor research and development. To develop a series of DRAMs, for example, Samsung Electronics needed not only

US-trained Chin Dae-Je, Hwang Chang-Kyu, and Kwon Oh-Hyun as heads of each developing team, but also scores or even hundreds of well-trained rank-and-file engineers and scientists. Moreover, both government and industry were ambitious enough to want South Korea to develop the full semiconductor production process – not only manufacturing chips but also designing them – just as American and Japanese semiconductor companies did at the time. Who, then, could and would supply the many engineers and scientists necessary to accomplishing this mission? The academy!

South Korean industry and the government began to realize the importance of the academy only in the mid-1980s, when not only Samsung, Gold Star, and Hyundai but also several medium-sized companies entered the semiconductor market. This immediately created a serious shortage of skilled manpower, and many universities hurriedly established programs to train semiconductor specialists. However, it required a huge amount of money to set up even a 'minimum facility' tailored to semiconductor training, which most South Korean universities could not afford.[74] The only solution was to receive support from government or industry. The government had sufficient funding only for KAIST or SNU, and the electronics industry preferred to support proven programs, such as Kim Choong-Ki's group, rather than new ones. Therefore, industry money and pleas for cooperation concentrated on KAIST between 1985 and 1995, and KAIST carried out several joint projects and education programs for semiconductors during this period.

The strength of the academy in the triangular relationship increased in the early 1990s. It was during this period that SNU's semiconductor group presented a serious challenge to KAIST's dominance. Despite SNU's organizational shortcomings, preference for theory over practice, and lack of eminent leaders in semiconductor research, its indisputable fame, sheer size, and location in Seoul were enough to make both government and industry invest great sums in its semiconductor research and education. SNU also began to aggressively recruit young semiconductor specialists as its faculty members.[75] Several KAIST professors of electrical engineering soon recognized this threat but had no choice except to work harder and do better than the competition.[76] The government's much-enlarged R&D budget and the electronics industry's aggressive investment in semiconductor education also enabled other universities, such as Pohang University of Science and Technology (POSTECH), Hangyang University, Yonsei University, and Korea University, to develop and expand their special programs on semiconductors during the 1990s.[77] With these greatly enhanced educational bases, the academy could provide industry with enough manpower during the 1990s and thereafter.

In short, academia's primary contribution to the development of semiconductors in South Korea has been in education, not research. The exception to this occurred between 1975 and 1990, when Kim Choong-Ki's laboratory at KAIST unintentionally led the country's semiconductor research because industry didn't yet have enough skilled engineers to conduct its own research and the relevant government research institutes were not stable because of frequent mergers and separations.[78] By the mid-1990s, however, industry possessed more semiconductor specialists than the academy did: for example, in 1995 Samsung Electronics' semiconductor R&D center had 100 Ph.D.s and 400 M.A.s on its payroll.[79] Nevertheless, industry has continued to generously support research at the universities, largely because the primary goal of industrial research was (and still is) not to make new discoveries but to solve immediate problems. As one retired Samsung Electronics director indicated, it's cheaper and safer for a company to give a risky project to a university and see what happens than to carry out the project itself.[80] The academy is also an important place where more fundamental, large-scale research, such as nano-technology, is carried out with government support: accordingly, the Korea National NanoFab Center opened at KAIST in March 2005.[81] This division of research labor between the electronics industry and the academy seems to have worked well so far.

How, then, do we position Kim Choong-Ki within this triangular relationship among government, industry, and academia? On the one hand, Kim Choong-Ki was a major beneficiary of this unique triangular relationship. The Park government's creation of a new graduate-only institution, KAIST, enabled Kim to return to South Korea and train the first two generations of South Korean semiconductor specialists in a laboratory equipped with all the necessary facilities. It was also the South Korean government that continuously emphasized the importance of semiconductors in the 1970s and early 1980s, and prepared detailed plans to push the reluctant electronics industry into the semiconductor market. At the same time, Kim was a major beneficiary of the electronics industry, which welcomed his students and supported his research. He often told his students, 'Whatever the government prepared for the development of semiconductors and however much engineers led semiconductor technology, the memory business could not have grown so successfully if Lee Byung-Chul had not decided to invest in the memory business [in 1983]' – a very rare and frank recognition of the role of industry by a South Koran academician.[82]

On the other hand, Kim Choong-Ki was a significant promoter of this unique South Koran triangular relationship. Even though he was neither the first nor the only person to introduce semiconductor technology into South Korea, he was the first who systematically taught it at the graduate level there, as early as 1975. Moreover, Kim was the model teacher whom both the South Korean government and the electronics industry had sought for a long time: he taught his students both theory and practice, along with how to have and use a true engineer's mind. Most of his research papers dealt with practical subjects that could be applied to real problems in the semiconductor industry. This was especially evident when he and his students published their papers in Korean.[83] The South Korean government and the electronics industry had finally found someone who could and would provide the industry with practice-minded semiconductor engineers. The academy also discovered a model to emulate in order to produce semiconductor specialists for the industry. Since South Korea's human resources were limited and its companies very insular until the end of the twentieth century, training a sufficient number of 'Korean' semiconductor engineers was critical to the success of the semiconductor industry.

As virtually the sole teacher and researcher in semiconductors between 1975 and 1990, Kim Choong-Ki's contributions were significant enough to be recognized by the South Korean government, industry, and the academy: the government awarded him the Moran Medal in 1997; the Samsung conglomerate gave him its prestigious Ho-Am Prize in 1993; and Seoul National University (College of Engineering) honored him with a Distinguished Alumni Award in 1997, and KAIST thanked him with a Distinguished Professorship in 2007.[84]

Conclusion

The development of the South Korean semiconductor industry in the last quarter of the twentieth century is a unique story in which three different actors – government, industry, and the academy – played different roles but also cooperated and interacted closely with each other. Although in other countries the academy contributed less than the other two to the development of semiconductors and has hence been neglected when explaining the success of the South Korean semiconductor industry, it made surprisingly important contributions in the South Korean case. Moreover, Kim Choong-Ki was the most important semiconductor professor in South Korea during this period: he not only trained the first two generations of semiconductor specialists for the electronics industry but also proved the usefulness of the academy to both government and industry for the development of semiconductors.

Although the South Korean semiconductor industry comfortably dominates the world market today, the future is not so rosy. It actually faces many grave difficulties. The most serious challenge comes from China, which lists the development of semiconductors as its top priority in its ambitious 'Made in China 2025' plan: the Chinese government has already set up several 'public and private funds to develop its semiconductor industry' and aims 'to spend as much as $161 billion over 10 years to develop chips through M&A'.[85] With plenty of capital, a huge number of highly educated engineers and scientists (including American-trained semiconductor specialists), and a government-controlled domestic market, Chinese semiconductor companies may soon dominate China's own market, which has been South Korean semiconductor companies' major market since the beginning of the twenty-first century. The sudden decline of market share of South Korean mobile phones in China during the 2010s may therefore soon be repeated in semiconductors.[86]

The other serious challenge comes from inside. The close triangular relationship among government, industry, and the academy, which critically contributed in the development and success of the semiconductor industry in South Korea, has not worked well since the beginning of the twenty-first century, especially in the 2010s. The major culprit is the government, which has neglected its role of supporting both industry and academia with reasonable policies. Although the semiconductor industry has cried out for more highly skilled manpower for R&D and the academy has demanded more favorable policies for doing basic research and increasing the supply of semiconductor specialists, the South Korean government in the twenty-first century has done little in response. It also failed to maintain the favorable environment for science and technology in the twentieth century, which started the crisis of science and technology in the new century. The result is a severe shortage of semiconductor specialists with advanced degrees: the number of master's and doctoral degrees earned in semiconductors at Seoul National University, for example, decreased from 97 in 2007 to 43 in 2017.[87] In a small, highly centralized country like South Korea, this kind of problem cannot be solved without the involvement of government. Added to the challenge posed by China, this is an acute problem for the future of the South Korean semiconductor industry.

To overcome these two grave challenges, South Korea needs another leading figure who, like Kim Choong-Ki, has both the courage to break old traditions and a bold, prescient vision for the future. Just as South Korea needed the 'engineer-minded' Kim Choong-Ki in the 1970s, so it needs a 'creative-minded' new leader in the twenty-first century. A different time in a different environment requires a different leader.

Notes

1. For the worldwide market share of memory in the second quarter of 2017, see Semiconductor Business Intelligence, *Semiconductor Memory Market Shares Q2-2017*. For the top ten semiconductor companies in 2017, see Business Wire, *With Its Highest Growth Rate in 14 Years*.
2. Chosun-Ilbo, *Gongjang e ssaineun Jaego, IMF Sujun*.
3. Some examples are Kim, *Imitation to Innovation*; Lim, *Technology and Productivity*; Oh and Larson, *Digital Development in Korea*; Korea Electronics Association, *Gijeok eu Sikan 50 (1959–2009)*; Song, "The Growth of Samsung's Semiconductor"; and Chang, *Sony vs. Samsung*, 33–40.
4. Kim was the first engineer to receive this prize. See Joong Ang Ilbo, *Samhoe Ho-Amsang Susangja sunjeong*. For more details of Kim Choong-Ki's award, see The Hoam Foundations, "Previous Laureates." The prize was established in 1990 by Samsung chairman Lee Kun-Hee to commemorate his late father, Lee Byung-Chul, founder of the Samsung conglomerate, and is awarded each year to 'individuals who have contributed to academics, the arts, and social development, or who have furthered the welfare of humanity through distinguished accomplishments in their respective professional field'. It was originally divided into four areas—science/engineering, medicine, mass-media, and community service—but in 1995 science and engineering became separate areas. The awarding organization was also changed from the Samsung Welfare Foundation to the new Ho-Am Foundation in 1997.
5. Kyungseong Bangjik, *Kyungseong Bangjik Oshipnyun (1919–1969)*, 138–139.
6. Kim Joon-Ki, Choong-Ki's younger brother, was a computer scientist/engineer. He worked at IBM's Thomas J. Watson Research Center in Yorktown Heights, New York, for more than two decades. In 1997, the Samsung conglomerate invited him to join the company as a 'S[uper] class' scientist/engineer. Between 1997 and 2007 he worked at Samsung Advanced Institute of Technology and other related Samsung companies.
7. Jeon, "Interview with Kim Choong-Ki," 1. Jeon conducted a series of interviews of former chairmen of the KAIST Department of Electrical Engineering to write the history of the department. The recordings were transcribed and deposited at the department.
8. Kim, "Current Conduction in Junction-Gate Field-Effect," 2.
9. Boyle and Smith. "Charge Coupled Semiconductor Devices".
10. Engineering and Technology History Wiki, *Charge-Coupled Device*.
11. Jeon, "Interview with Kim Choong-Ki," 1. Fairchild was the first company to manufacture the commercial CCD in 1973. See Fairchild Image, *Our History*.
12. Gunsagar, Kim, and Phillips. "Performance and Operation of Buried Channel," 21.
13. Kim, Choong-Ki, and Dyck, "Low Light Imaging with Buried Channel"; Kim, "Two-Phase Charge-Coupled Linear Imaging".
14. Jeon, "Interview with Kim Choong-Ki," 5.
15. Ibid., 10–11.
16. Ibid., 4–5.
17. Ibid., 5.
18. One of Kim Choong-Ki's uncles reminded him of the sacred responsibility of Korean eldest sons. Author interviewed with Kim Choong-Ki on October 2011.
19. Jeon, "Interview with Kim Choong-Ki," 4.
20. Terman, et al., *Policy and Strategy for Science and Technology*, 40.
21. Kim and Leslie, "Winning Markets or Winning Nobel Prizes?"
22. Terman, et al., *Survey Report on the Establishment of the Korea*, 9.
23. The name of the department has changed several times in accord with organizational changes since its inception. For convenience, I adopt the name 'Department of Electrical Engineering', which is the wording that most KAIST professors and students commonly use.
24. Kim, "Guknae Bandoche Gongeop eu Baljeon Hoego".
25. See Seoul National University, *Seoul Daehakgyo Oshipnyeonsa*, 147–155. By the end of the 1970s, most professors in the SNU Department of Electronic Engineering had been trained in Japanese universities and few had received their doctoral degrees from US universities. It was quite the

opposite at KAIST, where most professors had received their doctorates from US or other Western universities.

26. Kim Ki-Nam studied LCD under Kwon Yeong-Se at KAIST and became a foremost specialist on memory. In 2014 he became a president responsible for the memory area at Samsung Electronics. In December 2018 he was promoted to vice-chairman of the company.
27. A notable exception was Kyungpook University. The South Korean government designated this university to specialize in electronics, including semiconductors, in the late 1970s. Many of KAIST's early master's degree holders, including Kim Choong-Ki's students, became professors there in the 1970s and 1980s.
28. Their master's theses included 'Design of an MOS Shift Register' (Chung Jin-Yong, 1976), 'Design and Fabrication of a Charge-Coupled Device' (Ju Dong-Hyuk, 1976), 'Characterization of Diodes for Integrated Circuits' (Kwon Oh-Hyun, 1977), 'A Study on the Integrated Injection Logic-Analysis and New Fabrication Process' (Seo Kwang-Seok, 1978), 'Design and Fabrication of a Seven Segment Decoder/Driver with PMOS Technology' (Rim Hyung-Gyu, 1978), 'Fabrication of the Integrated Injection Logic by New Process' (Han Chul-Hi, 1979), 'A 512-Bit Mask Programmable ROM Using PMOS Technology' (Shin Hyun-Jong, 1980), and 'The Design and Fabrication of 64-Bit Silicon-Gate N-MOS Static RAM' (Suh Kang-Deog, 1981).
29. Rim, Hyung-Gyu, "Cham Uni Joatda" [I Was Very Lucky] in Park, Sang-In et al. *Uri Kim Choong-Ki Seonsaengnim* [Our Teacher, Kim Choong-Ki], 29. The book is a privately collected memoir of Kim's former students that was dedicated to him on his sixtieth birthday.
30. Kim, "Guknae Bandoche Gongeop eu Baljeon Hoego," 440.
31. Seo and Kim, "On the Geometrical Factor of Lateral p-n-p Transistors,"; Kyung and Kim. "Charge-Coupled A/D Converter,".
32. Oh, Koh, and Kim, "A New P-Channel MOSFET Structure".
33. The Hoam Foundations, "Previous Laureates." For his research on the rapid thermal process, see Kim, "Rapid Thermal Processing for Submicron Devices"; Kim and Kim, "Two-Step Rapid Thermal Diffusion"; Kim, Lee, and Jo, "Metal Alloy and Implantation Annealing"; Jo, Choi, and Kim, "Slip Elimination in Rapid Thermal Processing".
34. The Ho-Am Foundation's website states in Korean that 'Professor Kim made excellent research achievements in semiconductor devices and integrated circuits through experiments despite very poor conditions for experiments in South Korea'. In the English version on the website, the phrase 'despite poor conditions for experiments in South Korea' is omitted. See The Hoam Foundation, "Previous Laureates."
35. The list of Kim Choong-Ki's former students at KAIST can be found in Park, et al., *Uri Kim Choong-Ki Seonsaengnim*, 134–135.
36. Park, et al., *Uri Kim Choong-Ki Seonsaengnim* (Kim Nam-Deog), 66.
37. Park, et al., *Uri Kim Choong-Ki Seonsaengnim* (Park Seong-Ge), 86–87.
38. Park, et al., *Uri Kim Choong-Ki Seonsaengnim*, 24–25, 27, 30–31, 62–63, 131–132, respectively.
39. Park, et al., *Uri Kim Choong-Ki Seonsaengnim* (Kim Jun-Ho), 106–107.
40. Six of these 72 master's theses were co-supervised with other professors in the KAIST Department of Electrical Engineering.
41. Chin, *Yeoljeong eul Gyeongyeong hara*, 175–176.
42. See ETRI, *ETRI Samshiponyunsa*, 130–131. In the early 1980s, Kim frequently brought his students to the KIET during the summer vacation to deepen their experience. See Park, et al., *Uri Kim Choong-Ki Seonsaengnim*, 51, 53, 58.
43. For more details, see KAIST, *Miraereul hyanghan Kkeunnimeopneun Dojeon*, 115–126.
44. Ironically, Kim Choong-Ki published more papers (23) in IEEE journals in the 1990s than in earlier decades. One of them, published in 1999, attracted special attention because the new technology presented in the paper was expected to help reduce the weight, electricity consumption, and cost of mobile phones. See Yoon, et al., "High-Performance Three-Dimensional". Yoon Jun-Bo received the third-place student prize at the symposium for this paper.
45. Kim and Leslie, "Winning Markets or Winning Nobel Prizes," 182. The interview was held on October 6, 1997 by Kim and Leslie.

46. See the official announcement by KAIST, posted by the Department of Electrical Engineering at https://ee.kaist.ac.kr/node/10278?language=ko.
47. A Ceremony in Honor of Professor Kim Choong-Ki, KAIST Archive, Video Footage 2_10237. According the South Korean law, all professors must retire at the age of 65. Kim's colleagues therefore prepared a special ceremony when he arrived at this age. As 'Distinguished Professor' he continued working in his laboratory at LG Innovation Hall (formerly LG Semicon Hall), which was constructed in 1997 with a donation from LG Semiconductor to train semiconductor designers and to accelerate the cooperation between KAIST and the semiconductor industry.
48. Landler, *The Silicon Godfather*; Reference for Business, *Morris Chang* (1931-).
49. Taiwan Semiconductor Manufacturing Company, *About TSMC: Pioneer of Dedicated IC Foundry Business Model*. The Taiwanese government provided the necessary funds for the establishment of TSMC, and remained as the largest stock holder after the company was privatized in the early 1990s. From the beginning, however, the government gave Chang free rein to manage the company.
50. For a brief biography of Simon Min Sze, see an official profile at the National Chiao Tung University, *Simon M. Sze*, and Computer History Museum, *Oral History of Sze, Simon*.
51. Okimoto, Sugano, and Weinstein, eds., *Competitive Edge*, especially Chapter 2: Background.
52. For American and Japanese efforts to develop VLSI semiconductors, see Okimoto, Sugano, and Weinstein, eds., *Competitive Edge*; and Sakakibara, *From Imitation to Innovation*.
53. For the development of the semiconductor industry in Taiwan, see Matthews and Cho. *Tiger Technology*, especially Chapter 4: A Cat Can Look at a King: How Taiwan Did It.
54. Oh and Larson, *Digital Development in Korea*, 36–37.
55. Government of the Republic of Korea, *The Fourth Five-Year Economic Development Plan*, 59 and 88.
56. Government of the Republic of Korea, *Electronics Promotion Plan*, 7. The report was prepared for the regular meeting of the ministers of economics, commerce, science and technology, etc.
57. Government of the Republic of Korea, *Electronics Promotion Plan*, 13.
58. Government of the Republic of Korea, *The Official Gazette*, *No. 8740*, 47.
59. Oh and Larson, *Digital Development in Korea*, 26. The government planned to invest about $400 million in the development of semiconductors, which was 'ten times larger than anything attempted up to then'.
60. Chun, *Chun Doo-Hwan Hoegorok*, 218–225. While collaborating to develop 4M DRAM under ETRI's management, Samsung and Gold Star secretly carried out their own programs to develop 4M DRAM with different methods.
61. KIET was merged with other related institutes to become ETRI in March 1985. For the History of KIET and ETRI, see ETRI, *ETRI Samshiponyunsa*.
62. For KIST and its sister institutes in the 1970s, see Monn, "Hankukgwahakgisulwon (KIST) ui Byeoncheon gwa Yeonkuhwaldong".
63. Kim, "Guknae Bandoche Gongeop eu Baljeon Hoego," 436–438.
64. Kim, *Imitation to Innovation*, 162–163.
65. ETRI, *ETRI Samshiponyunsa*, 48–49, 147–153. ETRI claimed that it created about USD 141 billion worth of economic effect between 1976 and 2011, among which semiconductor's share is about 12.5 percent, while telecommunication technology is about 66 percent.
66. For a brief history of the development of electronics in South Korea, see Korea Electronics Association, *Gijeok eu Sikan 50 (1959–2009)*. It was Gold Star that pioneered electronics with its first transistor radio in 1959.
67. These American companies built their production lines in South Korea in order to use its cheap labor. Few technology transfers were made by these companies during the 1960s and 1970s, and most of them moved to other countries in the 1980s.
68. Korea Electronics Association, *Gijeok eu Sikan 50 (1959–2009)*, 117–122.
69. For the establishment of Korea Semiconductor, see Samsung Semiconductor and Telecommunications, *Samsung Bandochetongsin Sipnyeonsa*, 88–92; Kim, "Guknae Bandoche Gongeop eu Baljeon Hoego," 439. Kang, the founder of Korea Semiconductor, wrote a private memoir, *Hankang eu Gijeok, Hankuk Bandoche* and uploaded it to the website (http://www.kdkelectronics.com/

korea_semi_pdf/kdk-2014-0823mm.pdf). He claims that the Samsung conglomerate stole his company.

70. Kim Kwang-Ho, who managed the semiconductor part from 1979 to the end of the 1980s, remembers the poor, almost devastating conditions with little support in the first five years. See Korea Electronics Association, *Gijeok eu Sigan 50 (1959–2009)*, 179–180.
71. Lee, *Hoamjajeon*, 233–244; Samsung Semiconductor and Telecommunications. *Samsung Bandochetongsin Sipnyeonsa*, 187–189; Samsung Electronics, *Samsungjeonja Samsipnyeonsa*, 198–201.
72. For the development of semiconductors at Samsung Electronics in the 1980s and 1990s, see Samsung Semiconductor and Telecommunications, *Samsung Bandochetongsin Sipnyeonsa*, 187–210 and 256–278; Samsung Electronics, *Samsungjeonja Samsipnyeonsa*, 198–212; Han, *Oebaljajeongeo neun Neomeojiji anneunda*; Kang, *Samsungjeonja Sinhwa wa keu Bikyeol*; Song, "The Growth of Samsung's Semiconductor Sector".
73. Successful semiconductor companies have also minimized the role of the government and overemphasized their leaders' wise decisions to enter the semiconductor business in the early 1980s: Samsung's official history, for example, repeatedly emphasizes Chairman Lee Byung-Chul's well-calculated but 'lonely' decision to enter the memory business in February 1983 (in the so-called Tokyo Declaration). See also Samsung Electronics. *Samsungjeonja Samsipnyeonsa*, 199–201, and Kang, *Samsungjeonja Sinhwa wa keu Bikyeol*, 203–219.
74. In fact, there was another way to train necessary manpower for semiconductor development. Samsung Electronics founded a 'corporate college' within the company in the late 1980s to train or re-train various engineers, including semiconductor specialists, but it was not so successful. Since the mid-1990s, the academy has taken up the task of training the necessary manpower for the semiconductor industry, and the corporate colleges have disappeared.
75. Between 1988 and 1996, for example, SNU's Department of Electronics Engineering alone recruited six semiconductor specialists, who made up almost half of its new recruits during the period.
76. For example, Lee Yong-Hoon remembered that SNU's Department of Electronics Engineering came to possess more professors and attract more research funds from the government and industry than his own Department of Electrical Engineering at KAIST from the mid-1990s on. See Jeon, "Interview with Lee Yong-Hoon," 10.
77. The South Korean expenditure for R&D increased rapidly during the period between 1980 and 2000: its gross expenditure started at $428 million in 1980, climbed to $4,676 million in 1990, and reached to $13,849 million in 2000. The ratio between government and private sector in this expenditure also changed: from the mid-1980s on, it was the private sector that invested more on R&D. For more information, see Lee, *Evolution of South Korea's R&D System*, 55. See also Arond and Bell, *Trends in the Global Distribution of R&D*, 19.
78. Although KAIST is a university, it has carried out a great number of research projects since its inception in 1971, which has often led to its being confused with KIST, the major research institute during the 1970s and 1980s. In fact, KAIST was the first research-oriented university in South Korea. For example, KAIST demanded that its doctoral candidates publish their papers in internationally renowned journals in English before graduation. For more details, see Kim and Leslie, "Winning Markets or Winning Nobel Prizes?" 170–176; and KIAST, *Miraereul hyanghan Kkeunnimeopneun Dojeon*, 171–193.
79. Lim, *Technology and Productivity*, 100–101.
80. Interview with an anonymous director of Samsung Electronics, conducted by the author (23 January 2011, in Boston).
81. For more details about the Korea National NanoFab Center at KAIST, see https://www.nnfc.re.kr. The Semiconductor Institute at Seoul National University entered into a cooperative contract with the institute in May 2005.
82. Park, et al., *Uri Kim Choong-Ki Seonsaengnim* (Yoo Yeong-Ok), 14.
83. For example, Kim Choong-Ki's group published 43 papers in Korean during the 1980s, and most of them were about the 'design', 'fabrication', or 'construction' of semiconductors.

84. The Moran Medal is the second highest medal in the Order of Civil Merit that is awarded to those who contribute significantly to the progress of politics, economics, society, education, or scholarship. The College of Engineering at SNU began to present the Distinguished Alumni Award in 1993, and Kim Choong-Ki was the first recipient who taught at a South Korean university (see http://eng.snu.ac.kr/node/13).
85. For a brief summary of 'Made in China 2025' in English, see US Chamber of Commerce, "Made in China 2025," 19. (https://www.uschamber.com/sites/default/files/final_made_in_china_2025_report_full.pdf).
86. The decline of the market share of South Korean mobile phones in China during the 2010s is striking. The market share of Samsung Electronics' mobile phone reached almost 20% in 2013, declined to 13% in 2015, and dropped to less than 2% in 2017 and 2018. See Hankyoreh. "Samsungjeonja Jungguk Smartphone Jeomyuyul 0% dae".
87. Joong-Ang Ilbo, "Bandoche Illyeok eopdaneunde gwaenchantaneun Jeongbu"; Joong-Ang Ilbo, "Bandochero meokgo saneunde Seokbaksa jeolban juleotda".

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