Economic Research Working Paper No. 27

Economics & Statistics Series

Breakthrough technologies – Semiconductor, innovation and intellectual property

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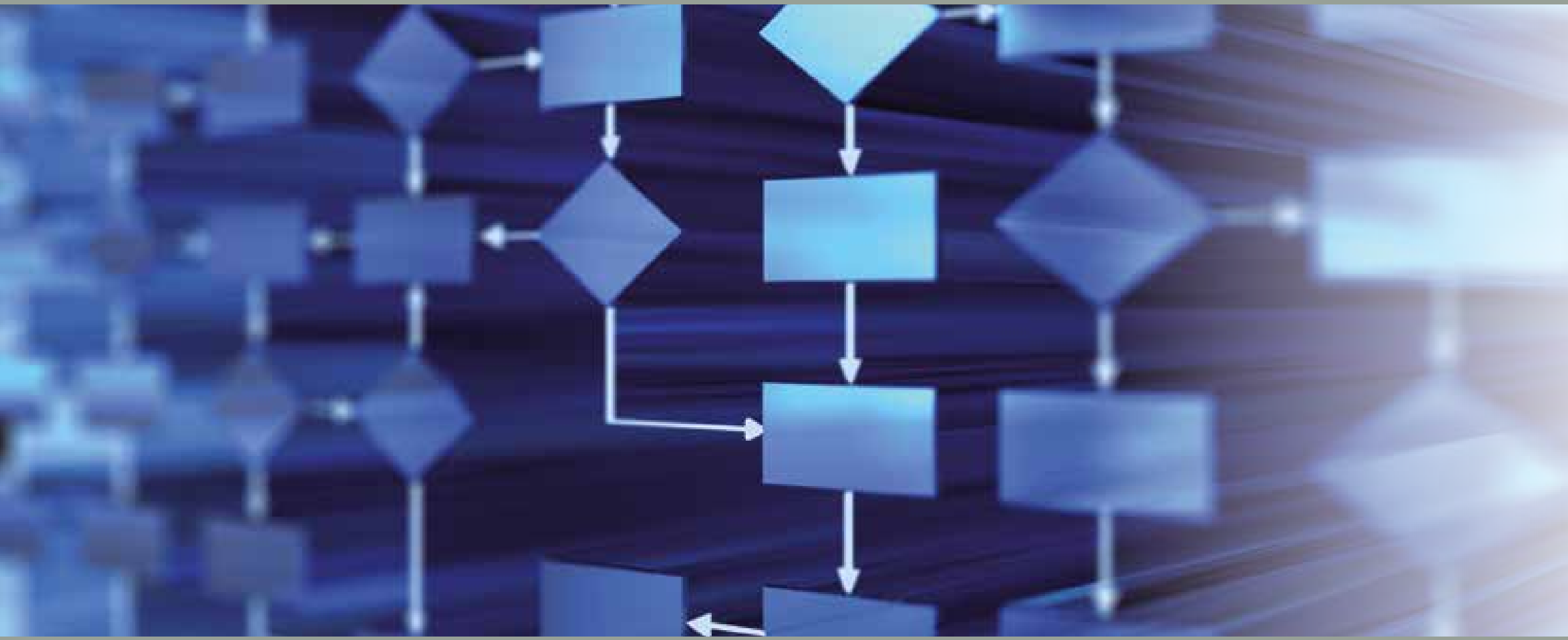

November 2015

WIPO
WORLD
INTELLECTUAL PROPERTY
ORGANIZATION

Breakthrough Technologies – Semiconductors, Innovation and Intellectual Property

Thomas Hoeren*, Francesca Guadagno**, Sacha Wunsch-Vincent**

Abstract

Semiconductor technology is at the origin of today's digital economy. Its contribution to innovation, productivity and economic growth in the past four decades has been extensive. This paper analyzes how this breakthrough technology came about, how it diffused, and what role intellectual property (IP) played historically. The paper finds that the semiconductor innovation ecosystem evolved considerably over time, reflecting in particular the move from early-stage invention and first commercialization to mass production and diffusion. All phases relied heavily on contributions in fundamental science, linkages to public research and individual entrepreneurship. Government policy, in the form of demand-side and industrial policies were key. In terms of IP, patents were used intensively. However, they were often used as an effective means of sharing technology, rather than merely as a tool to block competitors. Antitrust policy helped spur key patent holders to set up liberal licensing policies. In contrast, and potentially as a cautionary tale for the future, the creation of new IP forms – the *sui generis* system to protect mask design - did not produce the desired outcome. Finally, copyright has gained in importance more recently.

Keywords: semiconductors, innovation, patent, *sui generis*, copyright, intellectual property

JEL Classification: O330, O340, O470, O380

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Acknowledgements

Thanks to the Stanford Law School which allowed Prof. Hoeren to use the excellent library resources during his stay as a visiting professor at Stanford in 2014. Special thanks to Richard S. Stern and Steven F. Benz (Kellogg, Huber, Hansen, Todd, Evans & Figel, P. L. L. C.), Arno Körber (former head of the patent division of Siemens/Munich) and Mrs. Yuichi Utsumi (IEEJ/Toyko) for their comments.

The authors would also like to thank Dr. Roger J Burt (European and Chartered Patent Attorney and formerly Head of Intellectual Property Law, IBM EME) for co-reading the study and providing valuable advice as to the semiconductor industry and its use of IP. The authors are also grateful to Carsten Fink, WIPO, for his valuable comments, and to Julio Raffo, WIPO, for help in preparing the patent landscapes used in this paper.

A first draft of this study has been presented at a WIPO Workshop in Geneva – February 5 and 6, 2015.

Parts of this working paper were commissioned as background paper from Prof. Hoeren for the World Intellectual Property Report 2015: Breakthrough Innovation and Economic Growth.

Introduction

Semiconductor technology is at the origin of the development of the ICT industry and today's digital economy. The invention of semiconductors led to the rapid rise of mainframes and later personal computers (PCs), in turn giving rise to the informatization of entire industries, but also hospitals, schools, transport systems and homes. Semiconductors have had significant economic impact which continues to the present. The semiconductor industry itself has been growing for more than four decades.

This paper discusses the historical phases that marked the early breakthroughs and the development of what is today a multi-billion dollar industry. One main aim of the paper is to understand how historical innovation breakthroughs and their diffusion came about, also to better understand how future breakthroughs can be fostered. As semiconductor patenting and related litigation activity is regularly in the spotlight today, another aim is to obtain more clarity on the role of the intellectual property (IP) system for such breakthrough innovations. To that effect, the paper analyzes the early innovation system which characterized the rise of semiconductors, with a particular focus on the US, Europe and Japan. It also studies the use and role of IP as semiconductor innovation kicked off and thrived.

The remainder of the paper is structured as follows. Section 1 describes what semiconductors are and reviews the abundant literature on the contribution of semiconductors to economic and productivity growth. Section 2 describes the four historical phases that marked the history of the semiconductor technology. Section 3 illustrates the geography of innovation of semiconductors and discusses the most important characteristics of the innovation systems of the US, Europe and Japan, paying particular attention to the role of the government in stimulating innovation and research. Section 4 discusses how IP strategies and legislations evolved, leading to the creation of a *sui generis* protection for the layout of semiconductors. Some conclusions are drawn at the end of the paper.

This is part of a broader series of studies for WIPO's *World IP Report 2015* exploring the concrete linkages between innovation, IP, and growth in six areas of breakthrough innovation (airplanes, antibiotics, semiconductors, 3D printing, nanotechnology and robotics).

1. The semiconductor technology and its economic contribution

1.1. What are semiconductors?

Semiconductors, commonly known as chips or microchips, are needed for data processing, such as in PCs, laptops and servers. They are also integrated in communication devices such as mobile phones and in consumer electronics such as TV sets, gaming consoles and household appliances. Indeed, the invention of integrated circuits (ICs) was one of the main drivers behind the development of the broader ICT and consumer electronics industry, including for broadband and increasingly mobile applications. Often forgotten is the use of microchips in cars and industrial devices such as rail services, military and smart grids.

Semiconductors include vacuum tubes, transistors, ICs and microprocessors. The name "semiconductors" comes from the type of materials used in these devices. Some materials, such as silicon, can conduct electricity only under certain conditions, meaning that these materials change their electrical status. This characteristic places them between insulators and conductors. This property makes semiconductor materials good media for the control of electrical current and allows semiconductor devices to switch, amplify and convert electrical current.

Put simply, microprocessors consist of a large number of ICs, which in turn are nothing more than bundles of lots of linked transistors on a chip. They consist of silicon dies on which ICs are "printed". The circuits are put on the wafer by specially created patterns, the masks. The three-dimensional disposition of the pattern, which defines the structure of the circuit, is called layout design or topography.[1]

1.2. The economic contribution of semiconductors

Semiconductors have had significant economic impact. Until the 1970s, semiconductor devices were used to generate and control electrical current and to detect radio signals. Various industries, such as transports, chemicals and aluminium, adopted semiconductor devices with huge productivity gains. Later on, semiconductors triggered the development of the ICT industry. ICTs and the Internet transformed existing industries and created entirely new ones, for example in retail, distribution, energy, finance, transportation and health. As computing power grows exponentially, and as the size of chips is falling, the use of chips in non-ICT products such as cars, planes and fridges is increasing. Thus, semiconductor research also takes place in non-ICT industries. A sign of this phenomenon is the increased number of semiconductor first filings with forward citations, including from non-semiconductor patents (figure 1).

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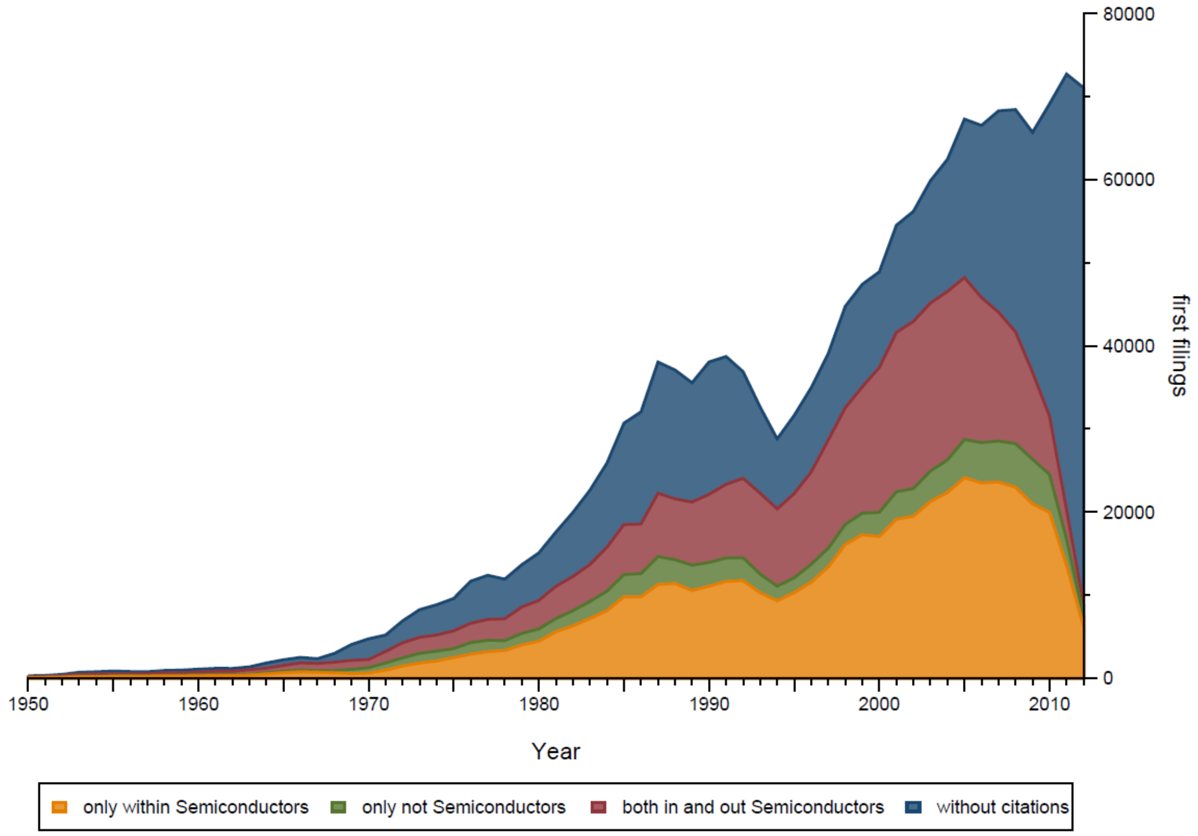
[1] Wolf and Tauber (1986).

Figure 1: First filings with forward citations from non-semiconductor patents increased

Number of first patent filings with forward citations, 1945- 2005



Source: WIPO based on the PATSTAT database (see annex).

The semiconductor industry itself has been growing for more than four decades. The global semiconductor market is estimated at USD 347 billion in 2015, up from close to USD 3 billion in 1976 (see figure 2). Demand growth moved from computers and consumer electronics to automotive and wireless products.[2]

An important geographical shift has also taken place. In 1976, roughly 70 percent of shipments came from the USA, 20 percent from Europe and 5 percent from Japan. In 1990, the share of the US had fallen to about 30 percent, whereas Japan had increased its share to 40 percent. Since then, the shares of the US, Europe and Japan have all declined, while the broader Asia Pacific region – essentially China, Taiwan (Province of China) and the Republic of Korea – accounted for about 60 percent of sales in 2015. It has been estimated that in 2015, China is the biggest market for semiconductors followed by India, Russia and Brazil.[3]

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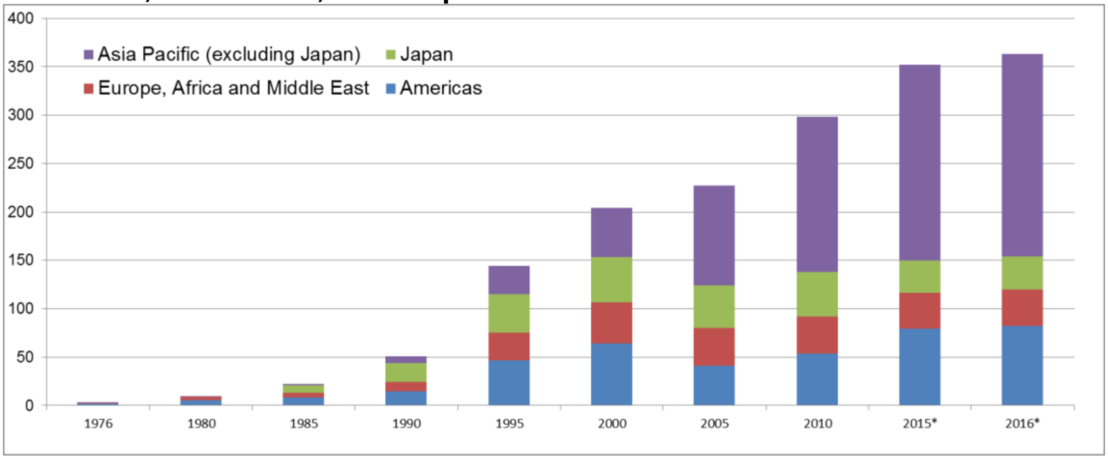
[2] WSTS (2015).

[3] PwC (2014).

Figure 2: Global semiconductor sales have increased rapidly, with strong regional variations
1976-2016, USD billion, current prices



Source: WIPO based on the Historical Billings Report and the WSTS (2015)

Notes: The regions here follow the definition of the WSTS. Years marked by * are estimates.

Economists quantified the contribution of ICTs to economic growth and identified three growth channels.[4] First, investments in ICTs contribute to overall capital deepening.[5] Second, technological progress in the ICT industry spurs TFP growth in the ICT-producing sector. The “quality” and speed of chips increases steadily while their cost falls, increasing their diffusion significantly.[6] Third, despite taking significant time, greater adoption of ICTs across all sectors of the economy raises economy-wide multifactor productivity. Firms and transactions become more efficient thanks to network effects too, as long as ICT investments are paired with organizational and process innovations.

Empirical studies confirm the existence of all three growth channels, but with some caveats, in particular as far as the third channel is concerned. There is consensus that since the mid-1990s the ICT-producing sector has made a considerable contribution to productivity growth in several high-income countries.[7] Indeed, ICT investment continued to positively affect value-added growth up beyond the last economic crisis.[8] I n addition, most studies conducted in the early 2000s in the US and for some other high-income countries demonstrate the strong effect of efficiency gains in the ICT-using, as opposed to ICT-producing, sectors, in particular the service sector.[9]

Rewards from ICT are not yet reaped by all countries. A concern has been that the ICT-driven productivity boost is not even as widely shared in Europe or in Japan than it is in the US.[10] Some studies also point out that the productivity impacts of ICT capital deepening in high-income countries may now have reached their climax.[11]

Semiconductors have started to diffuse to emerging economies, sometimes rapidly. In some low- and middle-income economies, ICTs have already had important effects in making markets more efficient, for example by creating new payment services or spurring further innovation. Undoubtedly, this potential in developing countries is far from exhausted. In terms of

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[4] OECD (2004) and Van Ark and Inklaar (2005).
[5] Stiroh (2002).
[6] Jorgenson (2001).
[7] Jorgenson and Stiroh (2000) and Colecchia and Schreyer (2002).
[8] Van Ark (2014).
[9] Jorgenson and Stiroh (2000), Pilat and Wölfl (2004), Bosworth and Triplett (2007), and OECD (2015).
[10] Colecchia and Schreyer (2002), Jorgenson and Motohashi (2005), and van Ark (2014).
[11] Gordon (2012) and van Ark (2014).

semiconductor production, economies such as China and Taiwan (Province of China), Malaysia and a few other Asian economies host some of the largest assembling and manufacturing activities. In terms of semiconductor innovation – and a few exceptions aside, including in China and some other Asian countries and in Latin America, notably in Argentina, Brazil and Costa Rica – higher value-added activities such as chip design still take place in high-income countries.

2. The development of semiconductors

The history of semiconductors can be divided into four historical eras: vacuum tubes, transistors, integrated circuits and microprocessors. While to some observers, the development of semiconductors was exclusively US-driven, as shown below, the story was far more complex and international than often conceived.[12]

2.1 Vacuum tubes (1901–1945): laying the scientific foundations for semiconductors

The first period of the history of semiconductors can be characterized as the period of individual researchers and entrepreneurs with strong egos. After Alessandro Volta used the term "semiconducting" for the first time way back in 1782, it took more than a century for the first US patent to be granted to the radio pioneer Jagadish Bose for his semiconductor rectifier as "cat´s whisker" crystal radio detector.[13] After that, research in semiconductors remained an issue for single researchers, who protected their inventions by patents.

In 1906, the American physicist Lee De Forest invented the vacuum tube triode which enabled amplification and switching of electrical signals. The First World War provided a strong stimulus to mass-production of amplifiers and development of new generations of better-quality amplifiers.[14] A greater interest existed, created, for example, by the growing volume of telephone traffic.[15] In 1930, Julius Lilienfeld received a patent for his basic idea of the solid-state transistor.[16] The big boom of semiconductors coincided with the Second World War when the US military forces needed special radar receivers which were able to detect and convert microwave signals.[17]

With industrial production, however, the deficiencies of the vacuum tubes became increasingly evident. The amplifier based on vacuum tubes helped to push the development of telephony and radio, but also computers. Although vacuum tubes were more reliable and allowed for more applications than previous technologies, the metal that emitted electrons in the vacuum tubes burnt out. The tubes were too big, not reliable enough and too energy-consuming.

Scientific discoveries by Max Planck, Albert Einstein and others laid the scientific foundations of semiconductor technologies. Europe was also active from the outset in the development of transistors. European scientists were working on solid-state amplifiers.[18] In 1934, Oskar Heil constructed and received a patent for a working field transistor *(Feldeffekttransistor)*.[19] When the excessive thoroughness of the German patent office delayed the examina-

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[12] For the different perspectives of US and Japanese scholars on the role of Japan, see Uenohara *et al* (1984).
[13] Lukasiak and Jakubowski (2010).
[14] Over one million amplifiers were produced during the First World War (Morris, 1990).
[15] Levin (1982).
[16] US Patent no. 1,745,175. See also Brinkmann *et al* (1997).
[17] Warren *et al* (1978) and Misa (1985).
[18] Riordan (2005).
[19] UK Patent No. GB 439,457. See also Arns (1998).

tion, he translated the application into English and filed for a patent in the UK.[20] The patent was issued within nine months. In 1938, two Germans physicists, Robert Pohl and Rudolf Hilsch, developed a solid amplifier, using potassium bromide as a semiconductor. In 1933, Pohl had made the visionary forecast that in the future, vacuum tubes would be replaced by semiconductors in radio receivers, provided that the movement of the electrons could be controlled.

2.2 Transistors (1945-1950s): from the Bell invention to innovation in (rival) firms

After the Second World War, Bell Telephone Labs, a subsidiary of AT&T, became the leading force for future development of the semiconductor industry.[21] In December 1947, Bell announced the development of the first successful transistor by three of its employees and later Nobel Prize winners, John Bardeen, William Shockley and Walter Brattain.

European researchers and firms were also sufficiently technologically advanced to be able to develop and produce transistors. In August 1948, the German physicists, Herbert F. Mataré and Heinrich Welker, employees of Compagnie des Freins et Signaux Westinghouse in Aulnay-sous-Bois, France, started an application procedure for a patent on "*le transistron*".[22] Transistrons were produced for and used by the French telephone company and the French military. This new term was used for an amplifier based on the minority carrier injection process. Their research was independent of and concurrent with the research by Bell Labs.

Only one week after Bell's announcement, Philips in the Netherlands produced a workable transistor, followed shortly thereafter by Thomson-Houston of France and GEC and STC of the UK.[23] The first solid-state radio receiver with four transistrons was presented at the Düsseldorf Radio Fair in 1953. In the meantime, in 1952, Heinrich Welker from Siemens identified gallium arsenide as a possible semiconductor. French and Germans were not the only one working on military applications of semiconductors. In the UK, military needs and efforts at Bletchley Park led to the development of the first electronic programmable computer, the Colossus.

Japanese scientists were active in semiconductor research since the development of the transistor.[24] In 1957, the Nobel Prize winner Leo Esaki of Sony discovered negative resistance characteristics in the current-voltage characteristics of very highly doped p-n junction. He reported this result at the fall conference of the Physical Society of Japan in the same year and also at the international conference in Brussels in 1958. This report was very much appreciated and used by William Shockley, one of the inventors of the transistor in the US. However, there was no clear patent strategy in Japan at that time. Esaki never asked for a patent, but shared his ideas with other international researchers. In 1960, a Bell employee filed a patent application for a device utilizing the Esaki effect.[25]

Transistors played a crucial role in the promotion of electronic devices. Their small size, low heat generation, high reliability and small power requirements made it possible to miniaturize complex circuitry such as that needed for computers. In addition, the US military forces and space agencies expressed their great interest in the new technologies and forced research-

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[20] Van Dormael (n.d.).

[21] For the role of Bell Labs, see Bernstein (1984) and Hornbeck (1985).

[22] Handel (1999), Markoff (2003) and van Dormael (2009). Van Dormael called Mataré and Welker the real owner of the Nobel Prize for the transistor. See van Dormael (2012) and van Dormael (n.d.).

[23] Malerba (1985).

[24] Nishizawa and Ouchi (1993).

[25] US Patent no. 3,058,064.

ers to focus on the miniaturization of microchips. As a consequence, since the mid-1950s, computers became more and more equipped with microchips.

In the meantime, engineers from Bell labs started to use photolithographic techniques to create patterns on printed circuit boards. This new technology helped to produce much finer designs on silicon. The desired structure was exposed on the photolithography coating layer, generally referred to as a resist, via an optical mask. Precise window sections were etched chemically where unexposed resist had been washed away leaving the exposed hardened resist. In 1957, this etching technology was granted patent protection.[26]

In 1959, Jean Hoerni, one of the co-founders of Fairchild, developed the planar transistor. Multiple transistors, resistors and capacitors were formed on a silicon wafer, connecting them by a conducting pattern of aluminum vias over a silicon dioxide film to form a circuit on a silicon die.[27] The planar transistor had considerable advantages in terms of reliability and costs, allowing for mass-production. Moreover, its technical components formed a circuit, bringing the industry closer to the next technological phase.

2.3 Integrated circuits (1960s): the rise of individual start-ups and the Moore's law

In July 1959, Robert Noyce from Fairchild filed a patent application for a "Semiconductor Device and Lead Structure".[28] This was the first model of an IC. The invention of Noyce was recorded only a few months after the key findings of Jack Kilby, an employee of Texas Instruments. Kilby had invented the monolithic integrated circuit by linking diodes, transistors, resistors and capacitors with aluminum metal lines on top of the protective oxide coating.[29] This involved creating electronic circuits on a semiconductor substrate by forming multiple circuit elements, such as resistors and transistors. The inventions of Noyce and Kilby were made independently of each other, so that Fairchild and Texas Instruments had separate patent rights.[30] These two patents became the basic patent coverage for ICs and the beginning of real business in the Silicon Valley. [31]

The price of the IC was competitive compared with discrete transistors, ensuring a rapid diffusion of the technology and especially its use in mainframes for military purposes or large businesses, and much later in large computers in firms and laboratories. Further miniaturization and increased computing power of ICs became the target of the semiconductor industry. The 1965 prediction of Gordon Moore, one of the founders of Fairchild Semiconductor and Intel, that the number of transistors on a single chip would double every 12 months – which he later revised to every 24 months – quickly became a reality, and is known to this day as Moore's law.[32]

Independent research conducted in Europe was leading scientists in a similar direction. In 1952, the British physicist G. W. A. Dummer proposed to integrate the transistor in a solid block without any connecting wires. In his eyes, the functional elements should have been connected directly by cutting out areas of the various layers.[33] The UK company Plessey, rather than Dummer himself, implemented this vision and produced the world´s first model of

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[26] US Patent No. 2,890,395.
[27] This description is based on Semiconductor History Museum of Japan (2011).
[28] US Patent No. 2,981,877. For a biography of Robert Noyce, see Berlin (2006).
[29] He received the Nobel Prize in 2000 for his invention (Lécuyer, 2006).
[30] That led to a long judicial litigation, decided by the United States Court of Customs and Patent Appeals. The Court decided in favor of Noyce on the basis the too broad wording of the Kilby patent, see Noyce v. Kilby, 416 F.2d 1391 (C.C.P.A. 1969).
[31] The story of who invented the IC is much more controversial than that (see Lojek, 2007 and Saxena, 2009).
[32] In April 1965, the Electronics magazine asked Moore to make a prediction on the future of the technology. For more details on the Moore's law, see Terman and Lanzerotti (2006) and Ballhaus *et al* (2012).
[33] Dummer (1952) and Green (2013).

an IC which was demonstrated at the 1957 International Symposium on Components in Malvern, the UK.[34]

While Japanese firms entered the semiconductor industry by producing transistors under license, they started their own R&D programs in the early fifties. At the outset, their budgets were rather low. In the mid-60s, R&D expenses amounted to two percent of sales, compared to six percent in the US.[35] Few patents were awarded in Japan before the mid-1960s (see Section 3). With time, Japanese firms became more innovative. The Sony TR55 portable was the first transistor radio made in Japan. It included two semiconductor diodes. NEC discovered a big potential market for desktop calculators; together with Hayakawa, the predecessor of Sharp, it developed calculators using MOS ICs. In 1960, NEC developed its first IC. In March 1964, Hayakawa sold the world´s first all-transistor desktop calculator. In 1968, NEC produced and integrated a memory card into a mainframe computer bought by NTT.

2.4 Microprocessors (1970s-1990s): the application of semiconductors to PCs

Texas Instruments and Intel both claimed to have developed the first microprocessor between 1970 and 1971. From the 1970s, Japanese producers developed and mass-produced microprocessors, becoming an important challenge to Intel and most US firms. In the meantime, process innovations and the development of computerized design tools enabled the task of chip product design to be split off from manufacturing. These important innovations allowed firms to specialize. They also created a market opportunity for new firms – especially in Asia – as these would mass-produce cheap chips for ICT production worldwide. Microprocessors enabled the rise of PCs, which spread computing to households and small businesses. Microprocessors were much more complex than ICs. A single chip included more than 100,000 components and gates.

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[34] Manners (2010).

[35] OECD (1968).

3. The semiconductor innovation system

The semiconductor innovation system evolved considerably over time, reflecting the move from early-stage invention and first commercialization to mass production and diffusion. The innovation system in each of the three main geographical regions – the US, Europe and Japan – had a very distinct structure. In the US, the Silicon Valley cluster created the conditions for specialized firms to emerge and coexist with large established firms. In Japan, large firms achieved large-scale and cheaper production and introduced innovations at both the technological and organizational levels. In Europe, a strong system of basic research, the dominance of large firms and a focus on consumer markets allowed firms to gain a strong competitive position in semiconductors for consumer industries.

All phases of semiconductor innovation, but in particular the early stage, relied heavily on contributions in fundamental science and linkages to public and university research. In addition, fast diffusion of knowledge spurred global innovation. Semiconductor innovation benefited from government support, in the form of demand for and purchase of semiconductor devices and industrial and trade policy.

3.1 The geography of innovation in semiconductors: early concentration in US, Japan and Europe and diffusion to Asia

Figure 3 depicts the number of first patent filings in semiconductor from 1945 to 2005. This period captures the time of invention – from the transistor in 1947 to the microprocessor in 1971 – and the subsequent period of diffusion. In the first period, the US and Japan led semiconductor patenting, followed by Germany, the UK, France and the Netherlands. Until 1971, US inventors filed on average 40 percent of all patents in the industry annually. Up to the 1960s, inventors of Japanese origin filed on average one percent of all patents; but by 1980, they filed 85 percent. The share of patents filed by inventors from the Republic of Korea was close to zero until the late 1980s, but 20 percent by 2005. The high shares of patents with Japanese origins are, at least to a certain degree, related to the practice of *patent flooding*, whereby Japanese firms filed many patents with minor changes on core technologies already patented by US firms. Features of the Japanese patent system allowed for this practice.[36]

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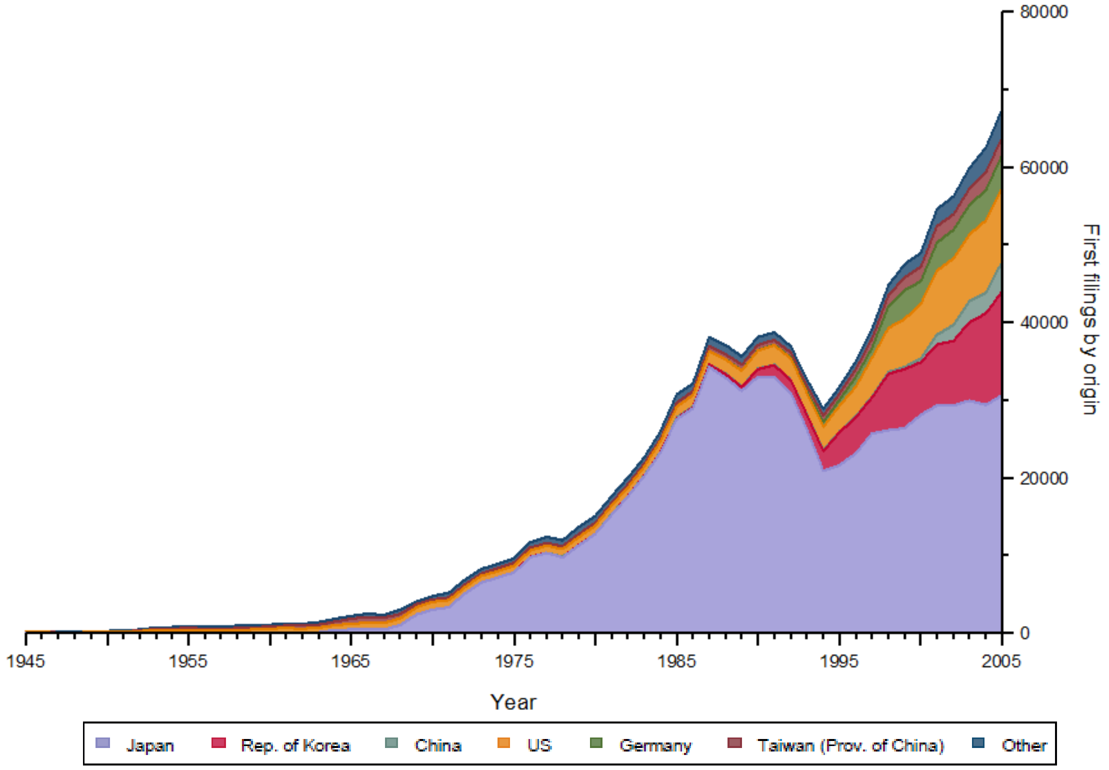
[36] See, for example, Wolfson (1993).

Figure 3: Fast growth in semiconductor patenting

Number of first patent filings by geographical origin of the applicant, 1945-2005



Source: WIPO based on the PATSTAT database (see annex).

Figure 4 depicts the origin of first patent filings in the period of invention between 1945 and 1975 (top) and contrasts this with the period from 1976 to 2005 (bottom). Three countries accounted for 89 percent of world semiconductor patents in each period. Between 1945 and 1975, these countries were Japan, the US and Germany, while in the second period they were Japan, the US and the Republic of Korea. In the second period, Taiwan (Province of China) and China joined the group of top six patent filers.[37] Other countries such as Singapore, Israel, the Russian Federation and middle-income countries including Malaysia, India and South Africa have also shown a growth in patenting, even if patent numbers are considerably lower.

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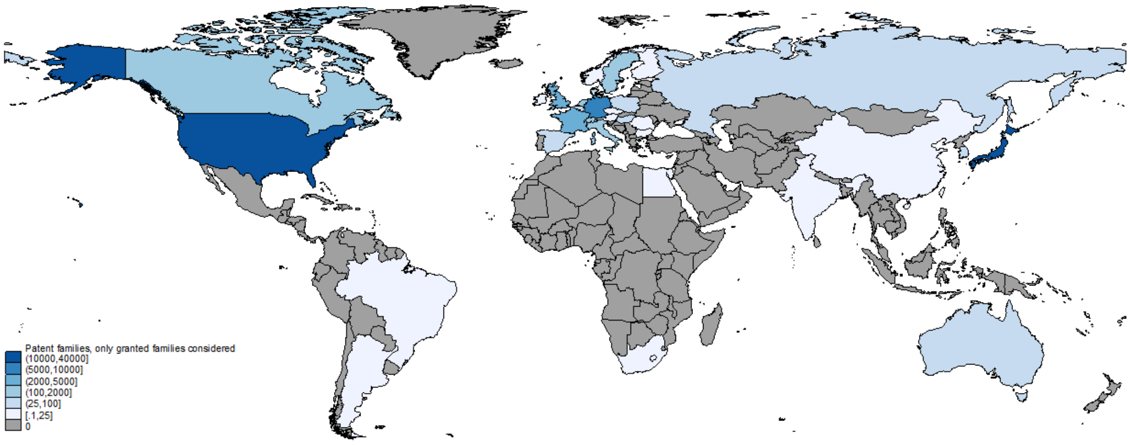
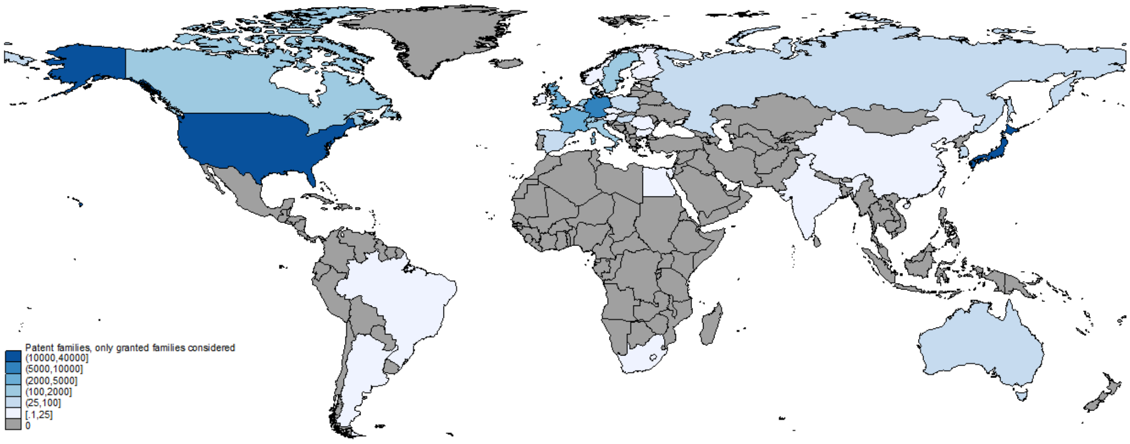
[37] For a reference on the Chinese semiconductor industry, see Ke (2012).

Figure 4: Diffusion from the US, Germany and Japan and other Asian countries 1945-1975



1976-2005



Source: WIPO based on the PATSTAT database (see annex).

3.2 The evolution of the semiconductor innovation system

The semiconductor innovation system evolved over the different technological phases described in section 1.

3.2.1 Vacuum tubes: large integrated firms and strong need for basic research

Large integrated firms – mostly electrical and electronic system companies, such as Western Electric in the US, Philips in the Netherlands, Siemens in Germany and Nippon Electric in Japan – produced most of the vacuum tubes. These firms constituted a stable oligopoly. US and European firms relied on their strong research units and linkages with universities.[38] At this time, the innovative efforts of Japanese firms were driven by the absorption of foreign technologies.

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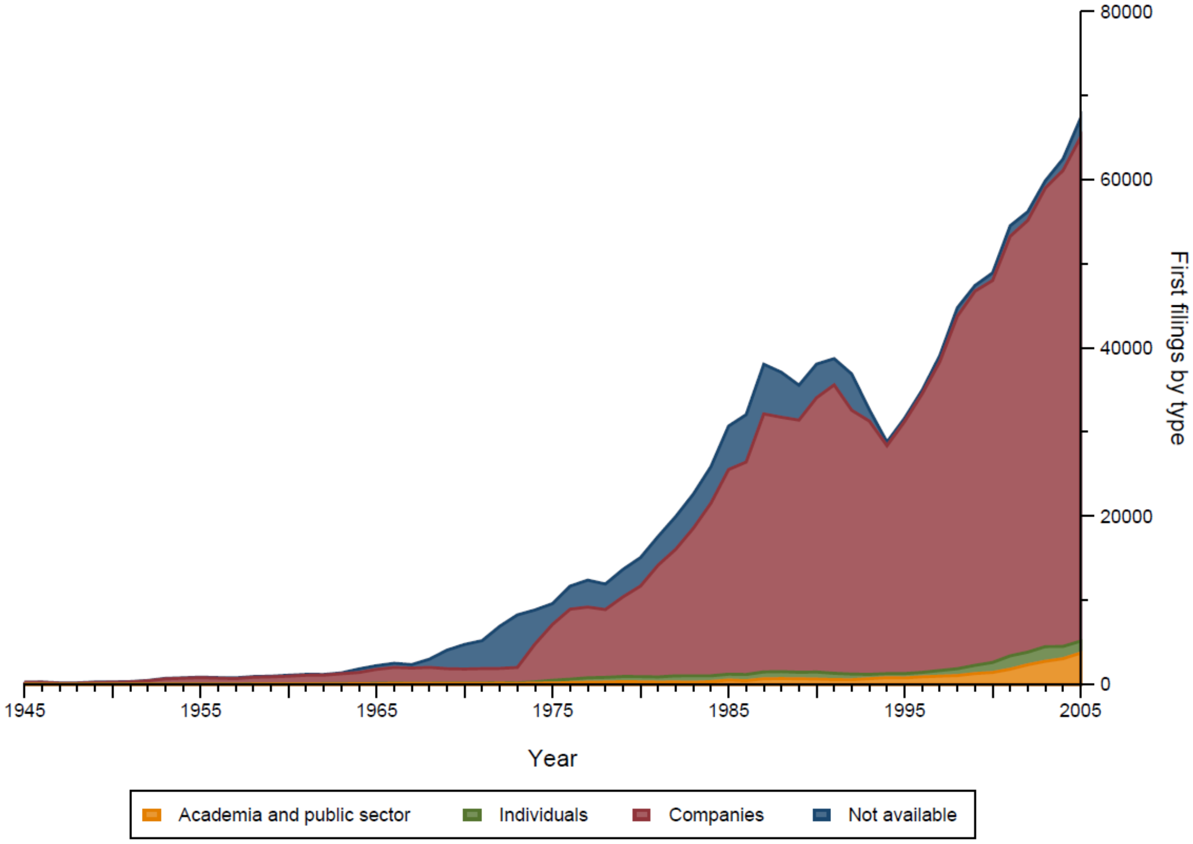
[38] For example, Lilienfield, the inventor of the first patent for a solid-state transistor, was professor of physics at Leipzig and Oskar Heil was a university professor at the University of Berlin (Morris, 1990).

3.2.2 Transistors: clustering and new entrants in the US

Interactions between scientific and technological knowledge were crucial for the development of new semiconductor devices. For example, in the late 1940s, researchers at Purdue University were remarkably close to inventing the transistor.[39] For example, in the US, universities such as Stanford University, MIT and the University of California, Berkeley formed a pool of knowledgeable scientists and engineers who attracted firms to locate in the same area. The interactions between basic and applied research were so important that large corporations had a corporate research laboratory – in AT&T's case, Bell Labs. Despite the strong role of universities and public research centers, it is interesting to note that the vast majority of patents were filed by firms (see figure 5).

Figure 5: Firms patent most of the semiconductor patents
First patent filings by applicant type, 1945-2005



Source: WIPO based on the PATSTAT database (see annex).

In the US, large vacuum tubes producers such as General Electric, RCA and Sylvania coexisted with new entrants. These were of two types: firms formerly engaged in other industries, for example Hughes and Texas Instruments, and firms established to manufacture semiconductors, for example Transitron.[40] In the early 1950s, vacuum tube producers represented around 75 percent of the US semiconductor production.[41] By contrast, start-ups had not produced vacuum tubes before and specialized in manufacturing new semiconduc-

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[39] Morris (1990).

[40] Hughes was a former aerospace and defence company, while Texas Instruments was a former geophysical service company.

[41] Tilton (1971).

tor devices. These firms had a substantial impact on advancing mainstream semiconductor technology along its dominant miniaturization trajectory.[42]

In the early 1950s, Japanese entered the semiconductor industry by producing transistors under license.[43] They produced their chips on the basis of the Bell licensing model (see below) and sent thousands of researchers to the US to attend conferences and visit plants.[44] In July 1956, five Japanese firms – Hitachi, Tokyo Tsushin Kogyo, Mitsubishi, Tokyo Shibaura Electric and Kote Kogyo – licensed US patents to produce special radio receivers.

In Europe and Japan, large integrated firms still led the industry, even if in Japan new entrants such as Sony created some rivalry. In Japan, Hitachi, Matsushita Electric, Toshiba, Nippon Electric, Mitsubishi Electric and Kobe Kogyo – today part of Fujitsu – were the first and major companies to produce semiconductors. However, the pioneer of commercial transistors was not one of these firms, but a new one, Tokyo Tsushin Kogyo, later renamed Sony. Small Japanese companies such as Sony focused on the production of small radios.

US firms predominantly served military agencies, while European and Japanese firms served the civilian market, in particular radios and televisions. By 1957, they were all active in producing chips for the internal and the international market. In 1958, five million radio receivers were produced in Japan. Around 1959, Japanese companies satisfied 50 percent of the US market for portable radios. By the end of the 1950s, Japan had become the largest manufacturer of transistors. The needs of military agencies differed considerably from those of radios and televisions. In Europe and Japan, costs, reliability and increased capacity to detect signals became the main focus of research and established germanium as the material of choice for transistors. In the US, size and power consumption established clear targets for new devices and led manufacturers to prefer silicon to germanium.[45] Later on, silicon became the dominant semiconductor material for most applications.

3.2.3 ICs: the start-up boom in the US and still little dynamism in Europe and Japan

The divergence between the US and the European and Japanese systems widened in the IC era. In the US, the IC market segment attracted the attention of many entrepreneurial scientists, who left large corporations to set up their own firms. In September 1955, William Shockley and Arnold Beckman founded the Shockley Semiconductor Laboratory as a division of Beckman Instruments in Mountain View. Shockley took advantage of the extra cleanliness of California, crucial to semiconductors' production, and the pool of scientists and engineers formed at Californian universities to establish and run his company.[46] Only two years later, eight of his employees, the "traitorous eight", left the company and founded Fairchild Semiconductor, which became among the most influential companies in the industry.[47] In turn, former employees of Fairchild and his competitor, Texas Instruments, founded a lot of small enterprises, like National Semiconductor, Advanced Micro Devices and Intel.

In 1977, the Federal Trade Commission noted: "The fact that companies can rapidly copy each other is very important. This rapid copying is the result of the mobility of personnel from firm to firm and the unwillingness of most firms to bring trade secrets or patent infringement suits. The rapid innovation and coping can also be explained by the number of times executive and technical personnel have left large firms to set up their own small, spin-

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[42] Levin (1982).

[43] Morris (1990).

[44] See the references to the Nippon Hoso Kyoku documentary series in Flamm (1996).

[45] Malerba (1985) and Langlois and Steinmueller (1999).

[46] Morris (1990).

[47] Motorola sued them for conspiracy, but lost the case. See Motorola, Inc. v. Fairchild Camera and Instrument Corp., 366 F. Supp. 1173 (D. Ariz. 1973).

off firms".[48] Most of the spin-offs were situated within a few square miles within the Santa Clara Valley in California. These events marked the rise of the Silicon Valley as the vibrant high-tech cluster that we know today. Personal mobility, facilitated by clustering and availability of risk capital encouraged this trend.[49] In 1966, in the US, major producers of semiconductors were specialized semiconductor firms – Texas Instruments, Fairchild and Motorola – followed by large electrical companies such as Western Electric and General Electric.

In Europe, consumer markets remained the major user of semiconductors. As a consequence, the major producers – Philips and Siemens – that had developed considerable expertise in using germanium, continued to mass-produce transistors and resisted the switch to silicon and ICs. While this partly occurred also in the US, start-ups ensured greater dynamism in the industry. European smaller firms, such as Plessey and Ferranti in the UK, COSEM in France and AEG-Telefunken in Germany, switched to ICs. However, their delayed entry and limited financial resources did not allow them to grow enough. Furthermore, consumer markets drove European firms to opt for analogue rather than digital ICs. These technological choices disadvantaged European producers as silicon and digital ICs came to dominate the industry. Consequently, the European markets for computer and digital devices were largely satisfied by imports from the US or by European-based subsidiaries of US firms, while European firms maintained a strong commercial position in consumer electronics. [50]

The Japanese semiconductor industry presented some commonalities with the European industry, despite being technologically less advanced. In continuity with previous eras, large integrated firms dominated the industry. Japanese firms were mainly vertically integrated: they not only developed, but produced and distributed chips and as well as the products embodying the chips. Firms focused on the consumer market, especially calculators, and were reluctant to move to silicon devices.

During this era, industry and university changed their strategies: firms became more interested in mass-production of microchips, whilst universities in special devices such as organic microchips. [51] At the same time, interactions between R&D and production intensified. For instance, Texas Instruments adopted an organizational structure that fostered relations between different divisions. This was one of the success factors of the company. [52] Similarly, in Fairchild Semiconductor, the invention of the planar transistor was the result of research efforts based on an intuition by a foreman in the production division. [53]

3.2.4 Microprocessors: towards an increased division of labor between design and production

In the microprocessor era, process innovations weakened the interdependencies between R&D and production. In addition, the complexity of microprocessors meant that greater capital investment was required for their manufacture. Consequently, the new system of innovation consisted of: firms that kept both production and design in-house, known as *integrated device manufacturers (IDMs)*, firms specialized in design, called *fabless* (fabrication-less) firms and firms specialized in manufacturing, the *foundries*. The application of semiconduc-

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[48] FTC (1977), p. 52.
[49] The agreement between the engineers leaving Shockley Semiconductors and Fairchild Camera and Instrument, the firm that financed the formation of Fairchild Semiconductor, was the first of its kind and contributed to the emergence of the venture capital business (Lecuyer and Brock, 2010).
[50] Malerba (1985).
[51] Levin (1982).
[52] Morris (1990).
[53] Lecuyer and Brock (2010).

tors to wireless communications and consumer products such as video games also contributed to specialization. These markets were much more fragmented and their product life cycle much shorter than computer markets.

In the US, Intel, the leader in the microprocessor market, and most semiconductor firms focused on design-intensive chips, yielding higher margins. Some of these firms, such as Intel and Texas Instruments, maintained their production facilities, evolving into IDMs. Others, such as Qualcomm, chose the fabless business model and outsourced manufacturing to silicon foundries.

Most Japanese firms, such as NEC, Toshiba and Hitachi, became IDMs, but focused on standardized semiconductor devices. Similarly, in the Republic of Korea, Samsung, Hyundai and LG Electronics became among the world leaders in memory chips sales. Foundries concentrated especially in Taiwan (Province of China). In 1996, the main foundries in Taiwan (Province of China) -Taiwan Semiconductor Manufacturing, United Microelectronics and Winbond Technology - produced 40 percent of the output required by US fabless companies. [54] In the late 1990s, firms from other Asian economies, such as Singapore, Malaysia, Thailand and China, entered the foundry business.

As in the past, US firms focused on computer applications, while Japanese companies on consumer electronics. The size and diversified nature of Japanese firms allowed them to rely on internal capital transfers in periods of sales downturns, guaranteeing stable and high investment rates. Japanese firms focused on quality control: the Total Quality Management practice promoted automated process control and monitoring. This had remarkable effects on improving quality and productivity. Another success factor of Japanese firms was the concept of life-time employment.[55] As a sort of tradition, Japanese workers did not change their jobs often because they were more interested in building a career within the same company during their life-time. Therefore, knowledge did not disseminate or got lost and the know-how could be kept in the company and transferred only internally.[56]

European firms adopted a strategy of acquisitions of US firms and R&D collaborations with established producers of microprocessors. This allowed them to use the new technology in consumer electronics, telecommunications and automotive applications. Philips, Siemens and SGS-Thomson maintained their commercial position in international consumer electronics markets and spun-off specialized semiconductor companies that later on became very successful.[57]

Until this time, the chip industry in the US was not organized and represented by a single industrial association. Since 1977, the Semiconductor Industry Association (SIA) has been its voice.[58] Founded by five microelectronics pioneers, SIA unites both manufacturers and designers, accounting for over 80 percent of the US semiconductor production. SIA kept a small size, to prevent itself from becoming large bureaucratic organization that could not pursue its mission. Its location in San Jose, California, rather than Washington, is emblematic of its need to stay close to its business.[59] Following the evolution of the industry, in 1994, six CEOs of fabless firms founded the Fabless Semiconductor Association (FSA) to promote the fabless business-model globally.[60]

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[54] Langlois and Steinmueller (1999).
[55] Abegglen (1973).
[56] Okimoto *et al* (1984).
[57] Malerba(1985) and Langlois and Steinmuller (1999).
[58] Langlois and Steinmueller (1999).
[59] Irwin (1996).
[60] In December 2007, the FSA became the GSA, the Global Semiconductor Alliance.

Table 1 summarizes the main characteristics of the semiconductor innovation system.

Table 1: The evolution of the semiconductor system

	Leading actors	Types of innovative efforts	Main users
Vacuum tubes	Integrated electrical firms (EU/US/JP)	Product innovation through scientific discoveries	Military radars (US) Consumer markets – television and radio (EU/JP) Power supply, transport and metal industries (EU)
Transistors	1. Integrated electrical firms (EU/US/JP) 2. Specialized firms (US)	Product innovation through applied research and engineering	Military uses and computers (US) Consumer markets – television and radio (EU/JP)
ICs	1. Integrated electrical firms (EU/JP) 2. Startups (US)	Product and process innovations, organizational and financial innovations	Mainframes and minicomputers (US) Consumer electronics (EU/JP)
Microprocessors	1. IDMs (US/ EU/JP/ KR) 2. Fabless firms (US) 3. Foundries (TW/SG/MY/TH/CN)	Product and process innovations, organizational innovations	PCs (US) Consumer electronics, telecommunications and automotive (EU) Consumer electronics (JP)

Notes: Abbreviations stand for: EU: Europe, JP: Japan, KR: Rep. of Korea, TW: Taiwan (Province of China), SG: Singapore, MY: Malaysia, TH: Thailand, CN: China.

3.3 The critical role of governments in financing and stimulating research and innovation

Governments spurred the development of semiconductors through various mechanisms with pronounced differences across countries. In the US, the first engines of innovation were military forces and space agencies, especially the Navy, the Army, NASA, the Atomic Energy Commission (AEC) and the Department of Energy (DoE).[61] The trend started during the two World Wars, when research aimed at improving radar systems.[62] In 1949, the government granted research funds to Bell Labs for the first time.[63] From 1956, more financing was directed to the new Silicon Valley start-ups.[64] Between 1952 and 1964, Signal Corps, the US military branch responsible for military communications, spent about USD 50 million for semiconductor engineering.[65] According to some estimations, the 1949 research grant to Bell Labs, the grants for R&D and manufacturing pilot contracts, and all other direct and indirect forms of financial support accounted for a quarter of all R&D in the industry in the late 1950s.[66]

Public procurement of semiconductors also played a crucial role in the US. The government and its military agencies ensured steady demand for US semiconductors. As a result of government purchases, production of rectifiers at Western Electric, the manufacturing arm of AT&T, increased 26 times from 1942 to 1945.[67] In 1952, all of the Western Electric´s sales and virtually all the other firms went to the military.[68] From 1955 to 1959, the US government purchased between 38 and 45 per cent of semiconductors' shipments.[69] Public procurement decreased in the late 1960s, as the Minuteman missile program and the buildup

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[61] See the figures in Flamm (1996).
[62] Levin (1982).
[63] Kraus (1973).
[64] Levin (1982).
[65] Braun and MacDonald (1982).
[66] Tilton (1971).
[67] Levin (1982).
[68] Kraus (1973).
[69] Levin (1982).

for the Vietnam war ceased.[70] The US government also favored the national industry through a “Buy American” policy. This made foreign bids less competitive than national bids, by requiring foreign firms to bid six percent under the lowest bid by an American firm.[71] Thanks to public procurement, the government also influenced the development of the industry by spelling out technical requirements. The very logic of miniaturization was a result of this. At least to a certain degree, commercial applications of ICs can be considered a spillover from military research.[72]

Government funding to private firms was combined with strong funding to – predominantly Californian – universities and research institutes, such as Stanford University, the University of California (Berkeley) and Caltech. These could benefit from a pool of young researchers educated at the Ivy League universities and ready to lead research in small university expert groups or start-ups. Government programs established laboratories and networks of research organizations. Research projects supported by the government focused on applied research, were interdisciplinary and involved close collaboration between researchers and manufacturers.

Spurring collaborative research, even among rival firms, was another important goal of the US policy for semiconductors. The 1984 National Cooperative Research Act facilitated joint research.[73] The government also established a number of projects, for instance the Semiconductor Research Corporation in 1982 and SEMATECH in 1987. The public research agency DARPA financed almost 50 percent of the SEMATECH budget and thereby gained access to all rights and trade secrets involved.[74] Spending more than USD 500 million, the aim of SEMATECH was to develop and produce ultra-thin circuity chips in response to the Japanese DRAM successes. Public funding was terminated in 1996, when foreign companies such as Hyundai, Infineon and STMicroelectronics joined the project.[75] In the literature, there is no consensus on the degree of success of SEMATECH, although most authors seem to evaluate it positively.[76]

Support continued with the establishment of the National Advisory Committee on Semiconductors in 1988. The Presidential Committee consisting of eight private CEOs and eight government officials was in charge of devising and promulgating a national semiconductor strategy. Between 1989 and 1992, it published a number of recommendations for strengthening the US semiconductor industry.

In terms of the regulatory environment, the 1956 antitrust Decree forcing AT&T to refrain from selling semiconductors commercially created a business opportunity both for large firms and start-ups. The US government also advanced the process of product standardization, allowing firms to enjoy a larger market and consequently benefit from economies of scale.

In Europe, no military contracts were available and, when support was available, little spillover to commercial applications materialized.[77] Governments did not devote the same financial resources to support the development of the industry. In 1965, government funding of R&D expenditures of semiconductor firms was USD 90 million in the US, USD 22 million in

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[70] Mowery (1994).
[71] Skole (1968) and Tilton (1971).
[72] Levin (1982).
[73] Langlois and Steinmueller (1999).
[74] SEMATECH (1998).
[75] In more recent times, new alliances, such as the Common Platform Consortium composed of IBM and Samsung and partnering with Toshiba, Infineon, Freescale, and STMicroelectronics have been formed (OECD, 2008).
[76] See, for example, Byron (1993) and Holladay (2012).
[77] See, for example, the case of the Colossus computer developed during the Second World War in the UK for code breaking.

the UK and USD 9 million in France.[78] Greater financial support arrived much later, when European firms were trying to catch up with US firms in microprocessors. The research laboratories set up by governments were keener on basic than applied research.[79] Subsidies, tariffs, non-tariff barriers and competition policies supported *national champions*. The limited scale of operations, due to the fragmentation of the European market, influenced the outcomes of these policies.[80] National procurement, for example in telecommunications, further deepened the fragmentation of the market.

Similarly to the European case, military procurement had no impact in the development of the Japanese semiconductor industry. The Japanese government exerted strong influence on the industry via its Ministry of International Trade and Industry (MITI).[81] Since the 1950s, MITI promoted the interests of the Japanese industry in various ways. In 1957, the Electronics Industry Promotion Law inaugurated MITI as the *genyoku*, the central leader of the electronics industry.[82] The law established the mechanisms through which MITI would support the industry, making financing for export expansion an important element of its strategy.[83] The 1957 program, together with the subsequent 1971 program, helped Japan to become one of the most important players in the global semiconductor industry. MITI initiated and financed cooperative projects.[84] In 1976, it established a consortium to develop advanced semiconductor technologies. The Very Large-Scale Integration (VLSI) consortium included a number of rival Japanese firms, namely Fujitsu, NEC, Hitachi, Mitsubishi and Toshiba.[85]

The Japanese government also favored the rise of a national industry through preferential treatment of national firms and capital controls to avoid the formation of wholly foreign-owned subsidiaries. It also controlled the licensing agreements between Japanese and US companies; agreements needed to receive official government permission. For instance, in the early 1960s, Texas Instruments was not allowed to establish a wholly-owned subsidiary. The Japanese patent office delayed the examination of its IC patent application for decades.[86] In 1968, after five years of negotiations, Texas Instruments agreed to form a joint-venture with Sony, with each firm holding 50 percent of the equities. It also agreed to license its IC patents to all Japanese companies. This deal and the years of negotiations provided the Japanese industry a chance to build up scale and capabilities before encountering foreign competitors.[87] This was not an isolated case; Fairchild was also refused an investment into its own IC plant.[88]

Until 1964, the Act on Foreign Capital regulated imports of foreign technologies. Imports had to be individually reviewed by the Foreign Investment Council before approval. The amount of foreign currency reserves in Japan was low and MITI published guidelines to control technology imports. The ministry had the advantage that the Japanese antitrust control system was rather lax at that time. The Japanese Fair Trade Commission faced issues regulating the relationships between the state and industry and almost never complained about the ac-

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[78] OECD (1968).
[79] Malerba (1985).
[80] Morris (1990).
[81] Johnson (1982).
[82] Flamm (1996).
[83] Langlois and Steinmueller (1999).
[84] Flamm (1988).
[85] The role of this consortium is disputed (Callon, 1995).
[86] But even then, Texas Instruments failed to enforce its patent rights in Japan. For instance in 1994, a Japanese court ruled that Fujitsu had not violated the Kilby patent, because the patent described particular technical details that Fujitsu did not use in two of its recent computer chips (Hayes, 1989 and Andrews,1994).
[87] Anchordoguy (1988).
[88] Flamm (1996). Further details can be found in Mason (1992). For the Japanese perspective, see Nakagawa (1985).

tivities of MITI.[89] The power of MITI was huge also because the Japanese state was highly centralized. Furthermore, the Japanese regulatory control is not achieved through unilateral decree, as in the US, but by voluntary compliance.[90]

Another important public actor of the Japanese innovation system was the national banking industry, which was heavily involved in promoting the semiconductors “made in Japan”.[91] Resources were made available for investment in new technologies. Japanese banks were permitted to hold private limited equity shares in companies to which they lent, unlike in the US where banks were prohibited from doing so under the Glass-Steagall Act of 1933.[92] Therefore, the banks could support Japanese firms even in times when there was no return on investment, leading to constant and high investment rates. This cooperation was based on the old corporate models in the Japanese society, *keiretsus*, informally linking firms with the Mitsui Bank.[93]

4. The role of the IP system

Through the various stages of innovation and commercialization, appropriation and IP strategies naturally evolved. They were often specific to particular actors, and varied significantly across countries too. A few broad characterizations are possible, however.

Semiconductor innovation coincided with the intense use of patents. All the phases discussed above witnessed numerous patent filings, most for inventions that were critical for the further development of the industry. Patent filings saw notable growth from the early days (figure 6).

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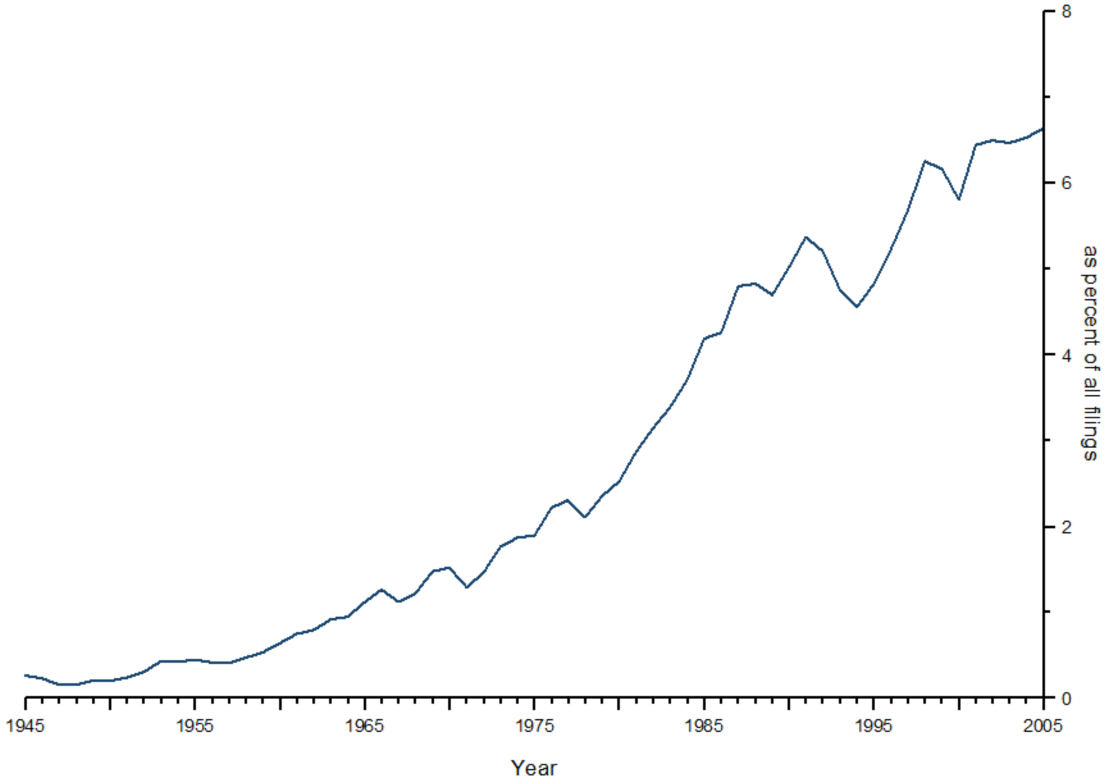
[89] Nakagawa (1985) and Okimoto (1989).
[90] Okimoto (1989).
[91] Flaherty and Itami (1984).
[92] Okimoto *et al* (1984).
[93] See the critical remarks by Miwa & Ramseyer (2001).

Figure 6: Increasing share of semiconductor patents in total patents
Semiconductor patent filings, as percentage of all patent filings, 1945-2005



Source: WIPO based on the PATSTAT database

This strong use of patents is striking as legally, the layout of semiconductors is in principle not protectable via traditional patent protection.[94] Indeed, layouts of ICs were considered obvious variations of prior layouts, and not deserving of patent protection.[95] Furthermore, some observers argued that the circuit layout could not be described in the form of a valid patent, in other words, verbally.[96] A drawing as such is not patentable and can only be used in the patent application for illustration.

From a business perspective too, the short commercial life of ICs also made other forms of appropriation more appealing.[97] Indeed, lead time, first-mover advantage, design capabilities and a good reputation were more important in this respect.[98] Nevertheless, other elements of semiconductor technology were patentable. In particular, patents were used to appropriate returns on technically complex structural features of semiconductor devices and innovations in semiconductor processing.

More importantly, patents were mostly used as an effective means of sharing technology among key actors. In part due to business strategy and government policy, patents rarely needed to be enforced. Firms were aware that chip development requires access to a multitude of overlapping inventions and rights held by diverse parties.[99] Firms directly or indirect-

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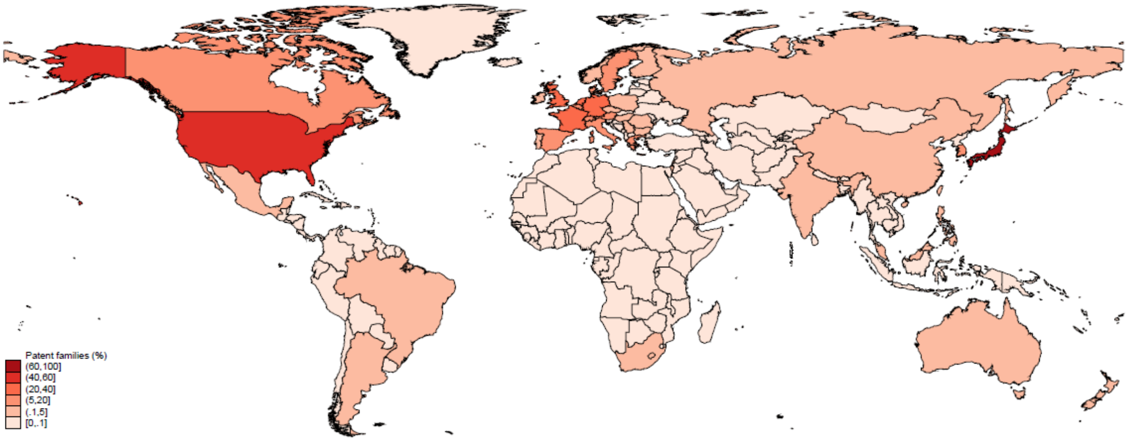
[94] Rauch (1993).
[95] Kukkonen (1997).
[96] Levin (1982).
[97] Lemberg (1987) and Risberg (1990).
[98] Levin *et al* (1987) and Cohen *et al* (2000).
[99] Grindley and Teece (1997) and Hall and Ziedonis (2007).

ly used other parties' inventions, either explicitly through flexible large-scale cross-licensing practices or implicitly by ignoring others' patent rights.[100]

Disclosure, the sharing of technology and the lack of litigation in the early periods facilitated cumulative innovation, and diffusion. Patents also facilitated specialization and helped to mobilize resources to cover the high R&D costs and to finance startups.[101] Indeed, the current build-up of large patent portfolios to block competitors or to avert the threat of litigation is – by historical standards – a newer phenomenon in the industry. The feared negative effect on true innovation might also be more contained than initially thought by some.[102]

As figure 7 shows, the US and Japan were the leading destination of patents up until the mid-1990s. In particular, in the period from 1945 to 1975, the US was the major destination of patent filings with 61 percent of applicants of first filings seeking protection there. The UK, Germany and France followed with between 40 and 38 percent of first filings. In the same period, the share of Japan was 28 percent. The tendency to seek protection mostly in the US and in Europe changed later on. In the period from 1976 to 2005, the leading destination of patents was Japan with 64 percent of all first filings, followed by the US with 52 percent. The share of patents seeking protection in Germany decreased to 24 percent. The Republic of Korea has the same percentage of patents seeking protection there, but its share in the previous period was only 0.2 percent.

Figure 7: The US and Japan are the major destinations of semiconductor patents Share of semiconductor patent families worldwide for which applicants have sought protection in a given country, until 1995



Source: WIPO based on the PATSTAT database

Laws protecting industrial designs, such as the Australian Designs Act and the British Registered Designs Act 1949, often are not applicable to tiny designs, such as microscopic engravings or designs within sealed containment. In addition, these regulations can only be used for the ornamental and aesthetic aspects of designs, excluding functional aspects. The same applies for copyright law. Generally speaking, the design of a microchip is itself not a suitable object of copyright law, due to its utilitarian nature.[103] It is in fact dubious whether

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[100] Von Hippel (1982), Appleyard (1996) and Motohashi (2008).

[101] Hall (2005).

[102] See, for instance, Shapiro (2000), Hall and Ziedonis (2001) and Jaffe and Lerner (2004) for related concerns.

[103] Universal Furniture Int'l, Inc. v. Collezione Europa USA, Inc., 196 F. App'x 166, 171 (4th Cir. 2006) (finding that furniture design is not copyrightable when the design aspects serve a mainly functional purpose), see also Brandir Int'l, Inc. v. Cascade Pac. Lumber Co., 834 F.2d 1142, 1143, 1148 (2d Cir. 1987) (holding that a squiggle-designed "ribbon" bicycle rack was a useful article and thus not copyrightable), ConWest Res., Inc. v. Play-

such designs embody artistic merits or reflect a certain degree of individual and personal creativity.

Few scholars discussed the role of trade secrets or the general application of rules of unfair competition law to protect semiconductors.[104] As patent law did not preempted state trade secrets law, many US states adopted the Uniform Trade Secrets Act (UTSA).[105] The UTSA expressly forbids disclosure or use of a trade secret of another without express or implied consent by a person who used improper means to acquire knowledge of the trade secret. Due to the high mobility of scientists in the Silicon Valley and the tendency of researchers to publish their discoveries, secrecy was not considered a viable strategy in the US. In the case of Japan, by contrast, employees benefited from lifetime employment and rarely left their company, keeping information internal. Hence, trade secrecy laws were rarely invoked. Finally, trade secret protection is not very helpful against reverse engineering of products sold in the market. As a consequence, trade secret laws seemed to be held to be inadequate.

The inadequacy of patent or copyright law systems to cope with microchips was the reason for the US government to create – and diffuse the adoption of – a new *sui generis* protection regime for semiconductors. As this discussion shows, it is helpful to distinguish the various phases of IP strategy carefully.

4.1 Phase 1 (1900-1940): individual academic undertakings with patents

In the early 20th century various academic inventors laid the foundations for the industry. Even at this early stage, inventions were often also filed as patents as well as being published as scientific papers. Yet these patents were not used exclusively by the inventor. In fact, they were mostly not commercially exploited at all; rather, they contributed to the pool of knowledge.

4.2 Phase 2 (1940-1980): patent equilibrium and extensive cross-licensing

The approach described above remained common in Europe, so that European researchers were talking about new concepts at conferences without seeking patent protection beforehand. As a result, it was not always clear who the first inventor of which element was. For instance, the name of William Shockley was left off the patent application after lawyers of Bell found that William Shockley´s writings on transistors were “highly influenced” by the 1925 patent granted to Julius Lilienfeld.[106]

In the US, instead, the situation changed during the Second World War, when the US military forces encouraged patent use.[107] In spite of this, the semiconductor industry was still characterized by its openness and transparency.[108] The technological features were devel-

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time novelties, Inc., 84 U.S.P.Q.2d 101, 1023-24 (N.D. Cal. 2006) (determining that design aspects of body part sculptures were not separable from their utilitarian functions). See Chesser (1985) and Kasch (1992). There are, however, court decisions, for instance in the UK, which held that mask works are protectable under copyright law in that chips may be considered "copies" of the technical drawings for the chips (L. B. (Plastics) Ltd. v. Swish Products Ltd. (1979)). The Swish doctrine is, however, very controversial even in the UK, see Green Paper on Reform of the Law Relating to Copyright, Design and Performers Protection (Cmnd 8302) and Hart (1985).

[104] See International News Service v. Associated Press, 39 S. Ct. 68 (1918) and Levin (1982).

[105] Supreme Court: Kewanee Oil Co. v. Bicron Corp., 94 S. Ct. 1879 (1974).

[106] Shockley (1950).

[107] Van Dormael (n.d.).

[108] The inventors of the Bell transistor did recognize the potential of their ideas (Lemley, 1997 and Lemley and Reese, 2004). Bell had a clear patent strategy, but did not enforce the patents via litigation. Furthermore, Bell had clearly foreseen the usability of the transistors in radio, phone and television.

oped by engineers especially in the US who claimed patent protection for essentials of their inventions, but opened their “books” for other researchers and firms throughout the world.

Bell Labs was especially active in disseminating knowledge about the new transistor technology. Bell organized three conferences for external scientists to get acquainted with new semiconductor technologies. The first meeting in September 1951 focused on military applications. In November 1951, it held a second symposium directed at US firms and focused on transistor applications. In April 1952, it welcomed over 100 scientists and engineers from 40 companies, including General Electric, Sony and Texas Instruments.[109] The three symposia were attended by representatives of universities and delegates of European and US companies. Japanese experts, instead, were not present.[110]

Those interested in the conference had to pay a patent-licensing fee of USD 25 thousands deductible against future royalties. They were allowed to attend the nine-day Transistor Technology Symposium, including a tour through Western Electric's transistor factory in Allentown.[111] The proceedings of these symposia, published as “The Transistor”, were informally called the "Ma Bell's Cookbook" and became the leading guidebook for the semiconductor industry in the 1950s. Since then, many US and international companies asked for licenses from Bell.[112] By agreement with the military, these were restricted to NATO countries.

Bell’s patents, licensed according to the Bell cookbook, were licensed on the condition the licensee made its own patents available at a fair price.[113] The IP system was considered to be too complicated and slow to cope with the necessities of the quickly growing semiconductor industry where small start-ups had a mentality of free exchange of ideas. As a consequence, the semiconductor industry extensively relied on the cross-licensing model.[114]

The establishment of this open strategy was also due to an antitrust policy: In January 1949, the Department of Justice opened an antitrust case against Western Electric and its parent company AT&T. AT&T and three other companies were accused of having established a patent pool in 1932.[115] The case was settled by a consent decree in January 1956, according to which AT&T agreed to grant royalty-free licenses on any patent issued before the time of the decree to any applicant. All future Bell patents were to be made available at reasonably royalties on any of its patents sought by the Bell system. In addition, AT&T and its subsidiaries were barred from engaging in any business other than the furniture of common carrier communication services and Western Electric was prohibited from selling semiconductors, except for government contracts. Due to this consent decree, the technological leaders in the industry, IBM and AT&T, were essentially curtailed from enforcing patent rights against rival firms.[116]

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[109] Chandler (2005).

[110] Official lists of attendees do not exist, only some conference photos are available. For details on the people attending the conferences, see Smits (1985) and Flamm (1996).

[111] Attendants were to a certain extent disappointed about the information policy of Bell. See for instance John Saby, inventor of the alloy junction transistor at General Electric: “In crystal growing, for example, Gordon Teal wrote papers on crystal growing, but never disclosed a lot of the details of the process to get the crystals to grow. People who grew crystals generally had to discover themselves, and people in academia were teed off by this because Bell would print all these things, but they didn’t really tell you how to make crystals that you could perform independent research on, unless you got down on your knees and ask them for a piece of crystal” (Morton and Saby, 2000).

[112] See Choi (2007).

[113] Levin (1982).

[114] Shapiro (2003) and Galasso (2006).

[115] Levin (1982).

[116] See Levin (1982) and Hall and Ziedonis (2007). AT&T applied this open strategy even in the 1970s, see Kerwin & DeFelice (2002).

In the literature, it was argued that this consent decree did little more than ratifying the existing corporate policy.[117] Back in 1949, Bell employees had already published articles arguing that Bell was willing: “to make available on reasonable terms to all who desired them non-exclusive licenses under its patents for any use”.[118] Bell traditionally asked for cross-licensing agreements.[119] The rationale for such a strategy was that the invention of the transistor and its consequences were so far-reaching that it was not wise to restrict access to the invention, as Bell could have not made all the technical contributions alone.[120]

Another event defined the IP strategy in the US semiconductor industry. In the mid-1960s, two big players, Fairchild and Texas Instruments, sued each other for patent infringement. In a 1966 settlement, each party dropped its opposition and agreed not to dispute its rival’s patents for a period of ten years.[121] The coincident claims of Texas Instruments and Fairchild and the balance of power between these two companies allowed disseminating the technology widely.[122] The companies closed cross-licensing agreements and invited others to join them in the diffusion of their results and advancement of the technology. As a result, existing patents were either cross-licensed or to certain degree ignored.[123] As statistics show, patent court proceedings started in 1973 on a very low level and increased only from 1983.[124]

At this time, arguments about trade secrets were unknown.[125] One of the big symbols of this spirit was the instrument of reverse engineering which allowed all semiconductor companies to check the interiors of circuits produced by competitors.[126] Years later, this practice was considered the “industry norm of competition”: “The industry spokespersons, while seeking protection from piracy as they perceived it, were insistent on preserving and encouraging the industry practices of creative copying, a practice known to them as reverse engineering.’’[127]

4.3 Phase 3 (1980-1984): initial closing-up as result of industrial policy and trade wars, and the creation of sui generis rights

The innovation and IP model described above began to erode, mostly as a result of industrial policy and the changing nature of technological leadership. In the 1980s, Japanese firms started to surpass US firms in the quality of semiconductor chips. This raised concerns in the US and accusations of IP infringement by Japanese companies were raised. From the early 1980s onward, semiconductor patenting and the propensity to patent accelerated to unforeseen levels in the US and abroad.[128] While existing IP rights *per se* were not ineffective, it was believed that a new *sui generis* right would have been more effective as it could be enforced internationally, on the basis of reciprocity.

The semiconductor *sui generis* protection right was conceived by Intel and its counsel Roger Borovoy. After a first attempt of the US Senate to extend copyright protection to ICs failed,

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[117] Levin (1982).

[118] McHugh (1949).

[119] Golding (1971).

[120] Tilton (1971).

[121] Finance (1975).

[122] Computer History Museum (1959).

[123] Von Hippel (1982) argues that simply ignoring imitation by infringement was a strategy. Reverse engineering was also common. Large Japanese firms were also fond of cross-licensing models (Appleyard, 1996 and Motohashi, 2008).

[124] Hall and Ziedonis (2007).

[125] However, companies such as Bell Labs had a clear sense of the importance of secrecy requirements prior to a patent application (Riordan and Hoddeson, 1997).

[126] For technical details on reverse engineering, see Schweyer (2012).

[127] Raskind (1985), p. 391.

[128] As documented in Fink *et al* (2015), the steepest increase in the ratio of first patents to R&D on a global level also occurred in the “electrical machinery, computer and audiovisual technology” category, which includes semiconductors.

the industrial associations representing the interests of the Californian semiconductor industry fought together with the US House of Representatives for a separate protection regime.[129] They used several arguments for that. First, they argued that the development of an IC involves around 500 process steps which take more than two years and embodies the know-how of thousands of engineers. Second, they stressed that it was technically very easy and rather cheap to copy these chips, while the development of new chips involved high costs.[130] This implied that US firms were exposed to an increasing number of imitators.

Furthermore, they held that existing national patent laws failed to give sufficient protection because they required high degrees of inventiveness. Patent protection seemed to be too complex and bureaucratic, especially the requirement of a full verbal description of the circuit layout.[131] As they argued in Congress, thousands of semiconductor devices need to be registered for patent protection in order to get protection for a single IC. The copyright system was also believed to be inefficient in cases of the copying of the pattern on the chip itself, if the pattern was deemed inseparable from the utilitarian function of the chip.[132] In addition, the final chip configuration is only the result of a great deal of technical drawings; unauthorized duplication is usually drawn from the finished chip and not from drawings or masks.[133]

An additional argument was the so-called “Japanese threat”.[134] At the parliamentary hearing, the president of Intel presented photos of a Toshiba chip, which according to his statement, was an exact copy of the Intel chip 2147.[135] The Toshiba chip remained the main evidence for Japanese piracy for decades.[136] As a matter of fact, the chips were indeed very different. Toshiba produced a smaller chip in a double metal process where the transistor patterns are organized in vertical columns. The Intel chip was bigger with horizontally organized transistors produced in a single metal process.[137]

Soon enough, the term “chip piracy” was invented. The term, however, was inappropriate, because in the lack of protection for chips, there could not be any claim of piracy. The House and the Senate discussed how to structure an effective system for fighting chip piracy. The Senate was opting for an extension of the copyright act.[138] The House was in favor of a new system of industrial property protection.[139] A new system of protection would have allowed the US to induce other nations to integrate this new protection system in their national legislation.[140] In addition, the copyright solution was held to be unviable, as the Universal Copyright Convention mainly relates to works of applied art and allows no other indus-

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[129] H. R. 1007, 96th Congress 1st Sess. (1979) adding to § 101 Copyright Act: “Such pictorial, graphic and sculptural works shall also include the photographic masks used to imprint patterns on integrated circuit chips and include the imprinted patterns themselves even though they are used in connection with the manufacture of, or, incorporated in a useful article”. See also Kastenmeier and Remington (1985).

[130] Industrial associations argued that the development of a chip costed USD 100 million, while imitators only had to spend USD 10 thousands or USD 50 thousands (Stim, 2012).

[131] Levin (1982).

[132] The Copyright Office had refused to register patterns on printed circuit boards and semiconductor chips, because no separate artistic aspects had been demonstrated (Committee on the Judiciary House of Representatives, 1983).

[133] Committee on the Judiciary House of Representatives (1983).

[134] Volokh (1988) and Rauch (1993).

[135] Committee on the Judiciary House of Representatives (1979).

[136] Years later, a second case was argued in the US press, where NEC was held to have copied the famous INTEL 8086 and 8088 microprocessors in their V20 and V30 (Morgan, 1983). In 1986, Intel sued NEC for copyright infringement regarding their microcode. In September 1986, Judge Ingram ruled that the electronic instructions, known as microcode, are eligible for protection under the copyright laws (Hinckley, 1987). However, this case only dealt with software piracy, not with the layout of ICs.

[137] Kasch (1992).

[138] This approach was taken in S. 1201, 98th Cong., 1st Sess., 130 CONG. REC. S5833-38 (daily ed. May 16, 1984).

[139] This model was used in H. R. 5525, *supra* note 1, 130 CONG. REC. H5524-25 (daily ed. June 11, 1984).

[140] H. R. REP Number 781, 7-8.

trial product to be protected.[141] At the end, the Congress favored the idea of a *sui generis* protection.

4.4 Phase 4 (1984 onward): semiconductor patent surge, defensive patenting and litigation

The Semiconductor Chip Protection Act (SCPA) of 1984 created a new kind of industrial property right, containing elements of patent, copyright and competition law.[142] Object of protection was the “mask-work”. The “mask” is the pattern used to set the circuits on the silicon-wafer in order to create the integrated circuit. The term “mask work” already demonstrated the traces of new *sui generis* right to copyright law.[143] Typical copyright terms were used when the act required the mask work to be “original”. However, the reference to mask works did not respect the original intention of the SCPA, which was to protect against illegal photos of the chip itself.[144]

The SCPA built on the notion of reciprocity. All nations were required to adopt the main elements of the SCPA. Otherwise, topographies and mask works of a foreign chip producer would not be protected in the US. Furthermore, the SCPA only grants interim protection where a state convinces the US Patent and Trademark Office that it is making “good faith and reasonable progress” towards providing protection on substantially the same basis.[145]

The provisions led to a legislative race against time in all parts of the world. Japan published an act similar to the SCPA as early as May 31, 1985.[146] In Europe, the EC member states established harmonized chip protection legislations to conform to the SCPA. Other European states, however, created their own systems to protect chips.[147] After interim protection in the US for nationals and residents of EC member states had been accorded to the EC Commission until November 8, 1987, the EC authorities hastily prepared a new Directive for chip protection.[148] The Directive on the Legal Protection of Semiconductor Products (87/54/EEC) was adopted by the EC Council on December 16, 1986 in order to harmonise the composition of legal protection for semiconductor technology.[149]

In the Directive, the EC authorities set some guidelines which have to be followed by the member states for protection in Europe:

(1) Not the microchip itself is to be protected but its “topography”; in other words, “the three-dimensional pattern of the layers of which a semiconductor product is com-

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[141] H. R. Rep Number 781, 7.

[142] Tide III of Public Law 98-620 of November 8, 1984, now 17. U.S.C. Section 901 et. seq.; *Industrial Property Laws and Treaties*, United States of America - Text 1-001. See also Woodson and Safreno (1985), Ladd *et al* (1986), and Stern (1986).

[143] Richard Stern sent T. Hoeren his comments on an earlier draft of this paper and noted here: “The Senate bill had “mask work” in it because Copyright Office General Counsel Dorothy Schrader objected to an early draft of the Senate bill, saying “where’s the ‘work’ to be protected as the scheme of the 1976 Copyright Act requires?” At that point, I said: “She wants a ‘work’? OK, she can have a ‘mask work’ if that will satisfy her.” So that ‘work’ went into the next draft of the Senate bill. The mask work concept had nothing to do with *sui generis*. It was an attempt to assimilate the chip protection sought to the copyright pattern of literary works, pictorial works, musical works, etc. But once in the Senate bill it stayed in and was carried over to the subsequent House bill”.

[144] Committee on the Judiciary House of Representatives (1979).

[145] Section 902 (a)(l)(2).

[146] Act concerning the circuit layout of a semiconductor integrated circuit (law number 60-43 of 1985).

[147] Such as the United Kingdom; see Hoeren (1992). Several states like the Netherlands, UK and Australia informed the US that they will simply apply their existing copyright legislation to microchips. Australia advised the United States of such intention in a communication described in 50 Fed. Reg. 24, 665 (1985), see also 50 Fed. Reg. 26, 818 (1985). The Netherlands advised the United States in a communication reprinted in 50 Fed. Reg. 24, 795, 796-800 (1985). The United Kingdom advised the United States in a communication described in 50 Fed. Reg. 24, 666-68 (1985).

[148] The first Interim Order has been issued on September 12, 1985 (51 Fed. Reg. 30, 690).

[149] *OJ,* L 24/36, January 27, 1987.

posed".[150] Unlike the SCPA, this definition does not use the term "mask work" to describe the object of chip protection, although the term is the same in substance. A topography is capable of protection if it is "the result of its creator's own intellectual effort and is not commonplace in the semiconductor industry" (Article 2 (2)).

(2) The right holder must be a national of an EC member state or has to start the commercial exploitation within the EC. Otherwise, the protection depends on special declarations of the member states in agreement with the Commission (Article 3).

(3) Article 5 provides the right holder with the exclusive right to authorize or prohibit the reproduction, commercial exploitation.

The EC member states had to implement this Directive into national law by November 7, 1987. The Federal Republic of Germany, for example, issued the *Halbleiterschutzgesetz* (Semiconductor Protection Act) in November 1987.[151] Essentially, most of these national acts repeat the wording of the Directive.

All these acts have a material reciprocity in common. This was a new way to induce other nations not only to accept, but also to adopt, new rights, provided that they wanted their own innovations to be protected as well. This new system of material reciprocity was harshly criticized in the literature.[152] According to some, it contradicted the principles of industrial property law. For centuries, the national treatment principle had been regarded the cornerstone of international patent and copyright law.[153] Inventions and copyright works had been protected irrespective of the nationality of their inventors.

The principle of reciprocity was integrated for the first time in industrial property laws.[154] Even in the US, experts feared that most other countries might have refused to adopt the US system. Thanks to the new system, if a country like Japan adopted the structure of the SCPA, US companies received protection for their mask works in that country. Otherwise, if the country refused to grant the protection, US companies could use the foreign mask works for free. The latter scenario, however, would have been highly unrealistic.

Mainly due to the new reciprocity rule, an international agreement on the minimum standards for semiconductor protection became necessary. In 1989, the "Treaty on the Protection of Intellectual Property in Respect of Integrated Circuits" (IPIC) was passed at the diplomatic conference of WIPO in Washington.[155] Although the treaty was accepted by the majority of the participating countries, it was never ratified, essentially because of the protests of the US and Japan.[156] The US especially criticized the duration of the protection which was set to be eight years (Article 8 IPIC).[157] It held that semiconductors such as computer chips have a longer lifespan. Japan and the US argued as well against the rules on compulsory licensing in Article 6 (3) IPIC.

After the failure of IPIC, the protection of semiconductors was regulated in Article 35 to Article 38 of the TRIPS Agreement. The TRIPS agreement integrates exemptions for "private

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[150] Art. 1(i) Council Directive 87/54/EEC of December 16, 1986 on the legal protection of topographies of semiconductor products.

[151] *Halbleiterschutzgesetz*, Bundesgesetzblatt, Part I, 2294 (1987). For a review of the protection system in the Federal Republic of Germany, see Hoeren (1988a).

[152] Hoeren (1988b).

[153] Dreier (1989) and Jehoram (1989).

[154] Dreier (1989). As Richard Stern (n. 1) explained in his comments on a former draft of this text, after the House´s decision to implement a sui generis right, "it became necessary to put in provisions about international comity".

[155] WIPO, Doc. IPIC/DC/46, under 8.

[156] Staehelin (1997).

[157] Hoeren (1989).

purposes", reverse engineering and innocent infringements.[158] However, Article 35 explicitly excludes the controversial Article 6 (3) IPIC which defines compulsory licensing. Furthermore, the IPIC article giving eight years protection was not implemented in TRIPS. According to the TRIPS agreement, each member state is free to decide about the implementation in its own legal system either as a *sui generis* law or in existent copyright or patent law.[159]

However, the structure of all these *sui generis* regulations was not very convincing. First, as Article 35 TRIPS Agreement states, it is not the semiconductor product itself which is the object of protection, but rather "the layout-designs (topographies) of integrated circuits".[160] This is slightly different from the wording of the US SCPA which protects the "mask-work". Moreover, in the TRIPS other methods to set the circuits on the wafer apart from "masks" are protected as well.

Second, the *sui generis* protection is combined with a joint copyright standard of "originality" and a patent law requirement of newness. This "originality" is the basic requirement for protection. The layout-designs are original "in the sense that they are the result of their creators´ own intellectual effort and are not commonplace among creators of layout-designs (topographies) and manufactures of integrated circuits at the time of their creation".[161] So, the topography firstly has to show minimal creativity in its design. Here the regulation uses the typical copyright standard of "intellectual effort". It further combines that standard with the additional requirements of not being "commonplace". This criterion resembles the patent law question of novelty, although the negative test of being not commonplace is a lower standard than the criterion of inventiveness. The latter requirement is more similar to those traditionally used in utility patent law. In this respect, the *sui generis* approach tries to combine copyright and patent law standards.

Another questionable element of this regulation is the provisions on reverse engineering, the act of creating a new topography by analyzing an existing one.[162] Reverse engineering, among the traditional ways of learning in semiconductors, is taken from the US SCPA.[163] According to Article 6 (2) lit. b IPIC, reverse engineering means that: "the third party *[…]*, on the basis of evaluation or analysis of the protected layout-design (topography) *[…]* creates a layout design (topography) complying with the requirement of originality *[…]*, that third party may incorporate the second layout-design in an integrated circuit". Thus, a third person is allowed to analyze the topography of a microchip from another producer in order to create its own new one. By contrast, simply rebuilding the same chip is not reverse engineering, because the topography of the new chip has to fulfill the requirement of originality (in the sense of Article 3 (2) IPIC mentioned above). Nevertheless, the principle of reverse engineering seems to be defined imprecisely, so that even mere copyists might refer to this principle in order to defend themselves against the right holder, if they can show a "paper trail" that proves lack of plagiarism.[164]

As already mentioned, especially the US and Japan criticized the term of protection in the IPIC Treaty. However, their critique can only partly be justified: While the lifespan of some microchips might be longer than eight years, the majority of microchips are far from being used longer than eight years. This is because of the fast rate of technological change in the chip industry and the fast development of new layouts. Nevertheless, the term of protection in Article 38 TRIPS Agreement was extended to ten years. Here, the same formula as in pa-

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[158] Article 6(2) lit. a IPIC Treaty, Article 6(2) lit. b IPIC Treaty, Article 6(4) IPIC Treaty, respectively.
[159] Hoeren (1989).
[160] Art. 35 TRIPS Agreement.
[161] Article 3(2) lit. a of the IPIC Treaty.
[162] See for the technical details on reverse engineering, see Schweyer (2012).
[163] Cf. 17 U.S.C. § 906(a)(2).
[164] Raskind (1985), Stern (1985), Brown (1990) and Hsu (1996).

tent regulations is used.[165] The earliest date on which the protection may begin is either "the date of filing an application for registration" or, "from the first commercial exploitation wherever in the world it occurs". Noticeably, in contrast to Article 8 IPIC, the date of creation of the layout would not be taken into account.

4.5 The use of the *sui generis* system for semiconductors

Since the mid-1990s, precisely since semiconductor protection was included in the TRIPS agreement, the uptake or actual use of the *sui generis* system is, at best, limited. Only a few number of chip layouts have been registered in recent years. For instance, in Germany the number of registered topographies decreased from 867 in 1999, to 444 in 2006, to 29 in 2012.[166]

Similarly, only a few decisions are known dealing with the *sui generis* regime. The Brooktree case was the only published US case on that matter. The jury ultimately issued a USD 26 million verdict against a chip rights' infringer which was upheld by a federal court of appeals.[167] Years later, the Ninth Circuit decided the case Altera v. Clear Logic.[168] Clear Logic was sentenced to pay USD 30 million to Altera for violating the SCPA. The argument of Clear Logic that they only copied abstract features, not protectable mask work, was dismissed, finding that "groupings" shown in the mask were "physically a part of the mask work" and were as such protectable.[169] In the case Nintendo Co. Ltd. v. Centronics Systems Pty. Ltd., the Australian Court decided in 1991 in favor of Nintendo and a Taiwanese chip producer.[170] The judge held that the visible differences of both layouts were insignificant design changes and that no evaluation or analysis had been carried out by the defendant.

Indeed, *sui generis* rights only protect the layout-design of an IC, but the IC function is more valuable than its design.[171] Layout-designs are easily to modify without loss of functionality and topographies are no longer protected once the design is altered, due to the provisions on reverse engineering. In addition, microchips, in other words their layout-designs, are highly complex miniature entities which are hard to copy.[172] This makes protection superfluous. An economic analysis of the factors which caused the failure of the *sui generis* right has never been conducted. This situation is similar to other new rights, such as the case of the Vessel Hulls Protection Design Act.[173]

4.6 The future of IP protection in semiconductors

Today, the *sui generis* right is an example of the creation of special IP rights that are rarely used.[174] Firms, instead, seem to rely more on patents.[175] This seems paradoxical, however.

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[165] "(…) shall not end before the expiration of a period of (…)", cf. Article 33 TRIPS Agreement.

[166] German Patent Office (various issues).

[167] Brooktree Corp. v. Advanced Micro Devices, Inc., 977 F.2d 155 (Fed. Cir. 1992).

[168] Altera v. Clear Logic, Case Nos. 03-17323, 03-17334 (9th Cir. Sept. 15, 2005).

[169] See also Avel Pty Limited v. Wells [1991] FCA 590, (1992) AIPC 90-846 (1991); 22 IPR 305; 105 ALR 635 (December 2, 1991).

[170] [1991] FCA 791, (1992) AIPC 90-854; 23 IPR 119

[171] See also Karnell (2001).

[172] Radomsky (2001).

[173] One of the most recent articles on semiconductor protection held that the US Act might be a model for regulating the protection of stem cells (Rose, 2012).

[174] See the former economist for the Semiconductor Industry Association, Steven Benz, in an email to the T. Hoeren: "As an antitrust litigator, I have been disappointed that there have not been more litigations to enforce mask work designs. The wave of SCPA litigation we predicted never materialized".

[175] See Hall and Ziedonis (1999). This led to the fact that the courts are now dealing with the patent rights of semiconductor producers, for instance the applicability of the first sale doctrine to chips. See the US Supreme Court decision Quanta Computer, Inc. v. LG Electronics., Inc., No. 06-937, 2008 U.S. LEXIS 4702 (U.S. June 9, 2008).

Indeed, to some observers, patent protection in semiconductors has met with mixed results.[176] After the creation of a "pro-patent" Central Appellate Court for the Federal Circuit (CAFC) in 1982, the number of patents filed by semiconductor producers visibly increased.[177] In an industry which previously has been among the least reliant on patents, there has been an upsurge in patents relative to R&D expenditure since the 1980s.[178] While companies relied more on patents, patents were considered to be the most ineffective tools for protecting knowledge in semiconductors.[179]

This paradoxical situation seems to be associated with a fear of a "race to the patent" and the existence of a "patent thicket" of prior art.[180] As a consequence, firms came back to the practices of the 1950s and the model of cross-licensing of patent rights, or covenants not to sue. [181] These contracts are linked to strong and extended trade secrets and confidentiality provisions.[182] In this open cross-licensing system, the patent itself plays a different role; it helps to avoid the risk of being sued for patent infringement and it is a source of revenues via licensing agreements. This defensive strategy also gives incentives to employees and helps monitoring the engineering process.

The IP system has also allowed an orderly development of innovations: the publication of the patent applications alerted researchers to the work being already done by others and supported a system where inventors nurtured mutual respect. The practice of cross-licensing is a great credit to the patent system, as the balancing payments enabled most R&D-intensive firms to partly fund their R&D expenditures. As Roger Burt – former IBM patent attorney – stated, the "IP system, and the patent in particular, is the lubricant that enable the engine of R&D to run smoothly".[183]

Today, the complexity of developing a semiconductor design cannot be controlled by a single country.[184] Future competition is not based on a single technology, but on product variety, combining pre-designed and pre-tested subcomponents. The increasing use of open source models for such components is already discussed in the literature.[185] As already discussed in Section 3, the system of innovation has changed as well. Today, fabless firms design chips which are produced by few big foundries, such as Taiwan Semiconductor Manufacturing Company (TSMC) and Globalfoundries. The netlists – the graphical descriptions of all the devices and connections between each device, given by fabless firms to foundries, which may include text, software, libraries and databases – are protected by copyright law, insofar as they include valuable and creative text-format converted chip designs.[186]

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[176] Mansfield (1981) and Roin (2014).

[177] See as leading case South Corp. v. United States, 690 F.2d 1368 (Fed. Cir. 1982).

[178] Hall and Ziedonis (2001).

[179] Cohen *et al* (2000, 2001).

[180] Merges and Nelson (1990) and Hall and Ziedonis (2001).

[181] Lewis (1995), Radomsky (2000), Ansari (2007), and Callaway (2008).

[182] Ludlow (2014) described this trend as "mega-licensing".

[183] Roger Burt has co-read this paper; the wording above has been used in an email to the author of February 25, 2015.

[184] Tuomi (2009).

[185] Greenbaum (2011).

[186] They can also be protected via encryption and watermarking (Schmid *et al*, n.d.).

Conclusion

Semiconductors have had a considerable impact in countries at all income levels, even though at different degrees. Semiconductors created entire new industries and transformed a high number of existing industries. Their use in our daily lives is pervasive, ranging from simple electronic appliances to computers and sophisticated machineries.

The semiconductor industry has been growing for more than four decades, becoming a multi-billion dollar industry. In the first phases of the development of the industry, the main countries that contributed to, and benefited from, new semiconductor technologies were the US, a bunch of European countries and Japan. Today, the industry is populated by players from all over the globe, including China, Taiwan (Province of China), the Republic of Korea, but also Brazil, Argentina, India, Russia and South Africa. Firms, universities and public research centers and governments contributed to research and innovation.

Over the years, not only the geography of innovation and production has changed from the period of vacuum tubes, but also the global organization of production and innovation evolved. Today, firms specialized in chip design, located mainly in high-income economies, cooperate with large chip producers, located mainly in lower-income economies. Knowledge and innovation diffused rapidly and the increasing number of applications of the technology allowed many firms to enter the industry and profit from its growth.

Patenting and related litigation activity in semiconductors is regularly in the spotlight today. In the early days, however, patents were used as an effective means of knowledge sharing. This fostered innovation and contributed to the technological advancement of semiconductors. The failure of *sui generis* rights to become the predominant protection mechanism for semiconductor firms poses questions on the efficacy of *sui generis* rights as viable alternatives to patents, copyrights and the other more “traditional” IP rights.

References

Abegglen, J. C. (1973). *Management and Worker – The Japanese Solution*. Tokyo: Sophia University.

Anchordoguy, M. (1988). Mastering the Market: Japanese Government Targeting of the Computer Industry*. International Organization*, *42* (3), 509- 543.

Andrews, E. L. (1994). Company News: Texas Instruments Loses in Japanese Ruling". *New York Times*. Retrieved March 17, 2015, from http://www.nytimes.com/1994/09/01/business/company-news-texas-instruments-loses-in-japanese-ruling.html

Ansari, M. (2007). "LG Electronics, Inc. v. Bizcom Electronics, Inc.: Solving the Foundry Problem in the Semiconductor Industry*". Berkeley Technology Law Journ*al, 22(1): 137-154.

Appleyard, M. M. (1996). How does knowledge flow? Interfirm patterns in the semiconductor industry. *Strategic Management Journal*, *17* (S2), 137- 154.

Arns, R. G. (1998). The Other Transistor: Early History of the Metal-Oxide-Semiconductor Field-Effect Transistor. *Engineering Science and Education Journal*, *7* (5), 233- 236.

Ballhaus, W., Pagella, A., Vogel, C., & Wilmsmeier, C. (2012). *Faster, Greener, Smarter – Reaching Beyond the Horizon in the World of Semiconductors*. New York: Pricewater-houseCoopers.

Berlin, L. (2006). *The man behind the microchip: Robert Noyce and the invention of Silicon Valley.* Oxford: Oxford University Press.

Bernstein, J. (1984). *Three Degrees above Zero: Bell Labs in the Information Age*. New York: C. Scribner's.

Bosworth, B. P., & Triplett, J. E. (2007). Services productivity in the United States: Griliches' services volume revisited*.* In E. R. Berndt & C. R. Hulten (Eds.), *Hard-to-measure goods and services: Essays in memory of Zvi Griliches* (pp. 413-447). Chicago: University of Chicago Press.

Braun, E., & MacDonald, S. (1982). *Revolution in Miniature: The History and Impact of Semiconductor Electronics*. Cambridge: Cambridge University Press.

Brinkmann, W. F., Haggan, D. E., & Troutman, W. W. (1997). A History of the Invention of the Transistor and Where It Will Lead Us. *IEEE Journal of Solid-State Circuits*, No.12, Vol. 32.

Brown, H. R. (1990). Fear and Loathing of the Paper Trail: Originality in Products of Reverse Engineering Under the Semiconductor Chip Protection Act as Analogized to the Fair Use of Nonfiction, Literary Works*. Syracuse Law Review, 41,* 985.

Byron, R. M. (1993). *SEMATECH – A Case Study: Analysis of a Government-Industry Partnership*. Retrieved March 17, 2015, from http://www.dtic.mil/dtic/tr/fulltext/u2/a273166.pdf

Callaway, D. (2008). Patent Incentives in the Semiconductor Industry. *Hastings Business Law Journal, 4*, 135-137.

Callon, S. (1995).*Divided sun: MITI and the breakdown of Japanese high-tech industrial policy, 1975-1993*. Stanford, Calif: Stanford University Press.

Chandler, A. D. (2005). *Inventing the electronic century: The epic story of the consumer electronics and computer industries*. New York: Free Press.

Chesser, J. (1985). Semiconductor Chip Protection: Changing Roles for Copyright and Competition*. Virginia Law Review*, *71* (2), 249- 295.

Choi, H. (2007). The Boundaries of Industrial Research: Making Transistors at RCA*.* 1948-1960. *Technology and Culture, 48*, 758- 782.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2000). Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent (or not). *NBER Working Papers*, No. 7552.

Cohen, W., Akira, G., Nagata, A., Nelson, R. R., & Walsh, J. P. (2001). R & D Spillovers, Patents and the Incentives to Innovate in Japan and the United States. *Research Policy, 31* (8-9), 1349- 1367.

Colecchia, A., & Schreyer, P. (2002). ICT investment and economic growth in the 1990s: Is the United States a unique case? A comparative study of nine OECD countries. *Review of Economic Dynamics, 5* (2), 408– 442.

Computer History Museum (1959). *Practical Monolithic Integrated Circuit Concept Patented*. Retrieved March 17, 2015, from http://www.computerhistory.org/semiconductor/timeline/1959-Noyce.html

Committee on the Judiciary House of Representatives (1979): "Copyright Protection for Imprinted Design Patterns on Semiconductor Chips." Hearings before the Subcommittee on Courts, Civil Liberties, and the Administration of Justice of the Committee on the Judiciary House of Representatives, 96th Cong, 1st Sess., on H. R. 1007 40, 59 (Dr. Andrew S. Grove).

Committee on the Judiciary House of Representatives (1983): "Copyright Protection for Semiconductor Chips." Hearings Before the Subcommittee on Courts, Civil Liberties, and the Administration of Justice of the Committee on the Judiciary House of Representatives, 98th Cong., 1st Sess., on H. R: 1028 77.

Dreier, T. (1989). National Treatment, Reciprocity and Retorsion - The Case of Computer Programs and Integrated Circuits*.* In F.-K. Beier & G. Schricker (Eds.). *GATT or WIPO? New Ways in the International Property of Intellectual Property* (pp. 63 – 70). Cambridge: VCH.

Dummer, W. A. G. (1952). *Electronic Components in Great Britain*. Proceedings of the Symposium on Progress in Quality Electronic Components, IRE, Washington D.C..

Finance, W. F. (1975). The International Transfer of Semiconductor Technology through US Based Firms. *NBER Working Paper No. 118*.

Fink, C., Khan, M., & Zhou, H. (2015). Exploring the worldwide patent surge. *Economics of Innovation and New Technology, in press*.

Flaherty, M. T., & Hiroyuki, I. (1984). Finance. In D. I. Okimoto, T. Sugano, & F. B. Weinstein (Eds.), *Competitive Edge: The Semiconductor Industry in the U.S. and Japan* (pp. 134- 176). Stanford, Calif: Stanford University Press.

Flamm, K. (1988). *Creating the computer: Government, industry, and high technology*. Washington, D.C: Brookings Institution.

Flamm, K. (1996). *Mismanaged trade?: Strategic policy and the semiconductor industry*. Washington, DC: Brookings Institution Press.

FTC (1977). *Economic report on the semiconductor industry: Staff report*. Washington, DC: Federal Trade Commission.

Galasso, A. (2006). *Cross-License Agreements in the Semiconductor Industry: Waiting to Persuade?*. Retrieved March 17, 2015, from http://www.inno-tec.bwl.uni-muenchen.de/files/service/links/epip/alberto_galasso.pdf

German Patent Office (various issues). *Annual Report*. German Patent Office, Munchen.

Golding, A. M. (1971). *The Semiconductor Industry in Britain and the United States: A case study in Innovation, Growth, and Diffusion of Technology.* PhD thesis, Sussex University.

Gordon, R. J. (2012). Is U.S. economic growth over? Faltering innovation confronts the six headwinds. *NBER Working Papers,* No. 18315.

Green Paper on Reform of the Law Relating to Copyright, Design and Performers Protection (Cmnd 8302).

Green, M. (2013). Dummer's Vision of Solid Circuits at the UK Royal Radar Establishment. *IEEE Annals of the History of Computing*, *35* (1), 55- 56.

Greenbaum, E. (2011). Open Source Semiconductor Core Licensing. *Harvard Journal of Law & Technology, 25,* 131-57.

Grindley, P.C., & Teece, D.J. (1997). Managing intellectual capital: Licensing and cross-licensing in semiconductors and electronics. *California Management Review*, *39* (2), 1- 34.

Hall, B. H., and Ziedonis, R. (1999). Patent Paradox Revisited: Determinants of Patenting in the US Semiconductor Industry, 1980-1994*. NBER Working Paper No. 7062.*

Hall, B. H., & Ziedonis, R. H. (2001). The patent paradox revisited: An empirical study of patenting in the US semiconductor industry, 1979-95. *RAND Journal of Economics*, *32* (1), 101- 128.

Hall, B. H., & Ziedonis, R. H. (2007). *An empirical analysis of patent litigation in the semiconductor industry*. Paper presented at the American Economic Association annual meeting, Chicago, IL.

Hall, B. H. (2005). Exploring the patent explosion. *Journal of Technology Transfer*, *30* (1/2), 35- 48.

Handel, K. C. (1999). Anfänge der Halbleiterforschung und -entwicklung: dargestellt an den Biographien von vier deutschen Halbleiterpionieren. PhD thesis, RWTH Aachen.

Hart, R. J. (1985). Legally Protecting Semiconductor Chips in the UK*. European Intellectual Property Review, 9*, 258- 263.

Hayes, T. C. (1989). Japan Grip Still Seen On Patents. New York Times. Retrieved March 17, 2015, from http://www.nytimes.com/1989/11/24/business/japan-grip-still-seen-on-patents.html

Hinckley, R. (1987). NEC v. Intel: Will Hardware Be Drawn into the Black Hole of Copyright Editors. *Santa Clara High Technology Law Journal, 3* (1), 23- 72.

Hoeren, T. (1988a). Der Schutz von Mikrochips in der Bundesrepublik Deutschland 3.

Hoeren, T. (1988). Das deutsche Halbleiterschutzgesetz vom 1.11.1987. Betriebs-Berater 1904.

Hoeren, T. (1989). Das Washingtoner Abkommen zum Schutz des geistigen Eigentums an integrierten Schaltkreisen. NJW 2605, 2606.

Hoeren, T. (1992). Chip Protection in Europe. In C. Prin and A. P. Meijboom (Eds.), *The Law of Information Technology in Europe 1992: A comparison with the USA.* Deventer, the Netherlands: Kluwer Law and Taxation Publishers.

Holladay, D. W. (2012). *Testimony before the Senate Committee in Energy and Natural Resources.* Retrieved March 17, 2015, from http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=aa4e2db1-2ae9-42a7-87be-7c4f21134524

Hornbeck, J. (1985). The Transistor. In F. M. Smits (Ed.), *A History of Engineering and Science in the Bell System: Electronics Technology, 1925-1975* (pp 1-100). Indianapolis: AT & T Bell Laboratories.

Hsu, L. (1996). Reverse Engineering Under the Semiconductor Chip Protection Act – Complications for Standard of Infringement. *Albany Law Journal of Science and Technology, 5*, 249.

Irwin, D. A. (1996). Trade Policies and the Semiconductor Industry. In A. O. Krueger (Ed.), *The Political Economy of American Trade Policy* (pp. 11 - 72). Chicago: University of Chicago Press.

Jaffe, A. B., & Lerner, J. (2004). *Innovation and its discontents: How our broken patent system is endangering innovation and progress, and what to do about it*. Princeton, NJ: Princeton University Press.

Jehoram, H. C. (1989). Some Curious Problems Caused by Semiconductor Chip Protection: A European View. *Journal of the Copyright Society of the U.S.A., 4,* 295 -299.

Johnson, C. (1982). *MITI and the Japanese Miracle – The Growth of the Industrial Policy, 1925-1975.* Stanford, Calif: Stanford University Press.

Jorgenson, D. W., & Stiroh, K. J. (2000). Raising the speed limit: U.S. economic growth in the information age. *OECD Economics Department Working Papers*, No. 261.

Jorgenson, D. W. (2001). Information technology and the U.S. economy. *American Economic Review*, *91* (1), 1- 32.

Jorgenson, D. W., & Motohashi, K. (2005). Information technology and the Japanese economy. *NBER Working Papers*, No. 11801.

Karnell, G. W. G. (2001). Protection of Layout Designs (Topographies) of Integrated Circuits – R.I.P.?*. International Review of Intellectual Property and Competition Law, 32* (6), 648.

Kasch, S. P. (1992). The Semiconductor Chip Protection Act: Past, Present, and Future*. Berkeley Technology Law Journal, 7* (1), 71- 105.

Kastenmeier, R., & M. J. Remington, M. J. (1985). The Semiconductor Chip Protection Act of 1984: A Swamp or Firm Ground?*. Minnesota Law Review, 70*, 417- 470.

Ke, R. (2012). *Comparison of China and Japan’s Economic Development in the Semiconductor Industry*. Retrieved March 17, 2015, from http://digitalcommons.bard.edu/senproj_s2012/342

Kerwin R. E., & DeFelice, R. A. (2002). Silicon for the Masses: How AT&T Licensed its IP in the 1970s to Facilitate the Development of a Worldwide Semiconductor Industry. In V. A. Kremeniuk & G. Sjöstedt (Eds.), *International economic integration: model versus reality* (pp*.* 229-244). Cheltenham: Edward Elgar.

Kim, S. R. (1998). The Korean System of Innovation and the Semiconductor Industry: A Governance Perspective. *Industrial and Corporate Change, 7* (2), 275- 309.

Kraus, J (1973). *An Economic Study of the US Semiconductor Industry*. PhD thesis, New School for Social Research, New York.

Kukkonen, C. A. (1997). The Need to Abolish Registration for Integrated Circuit Topographies Under TRIPS. *The Journal of Law and Technology, 38*, 105- 107.

Kurosawa, T. (1997). *Shirikon Kotohajime* [The Origin of Silicon Business].Tokyo: NEC Creative.

Ladd, D., D.E Leibowitz and B. G. Joseph (1986). *Protection for semiconductor chip masks in the United States: Analysis of the Semiconductor Chip Protection Act of 1984*. Munich: Max Planck Institute for Foreign and International Patent, Copyright, and Competition Law.

Langlois, R. N., & Steinmueller, W. E. (1999). The evolution of competitive advantage in the worldwide semiconductor industry, 1947-1996. In D.C. Mowery & R. R. Nelson (Eds.), *Sources of industrial leadership: Studies of seven industries* (pp. 19-78). Cambridge, UK: Cambridge University Press.

Lécuyer, C. (2006): Making Silicon Valley: Innovation and the Growth of High Tech, 1930-1970. Cambridge, Mass: MIT Press.

Lemberg, J. H. (1987). Semiconductor Protection: Foreign Responses to a U.S. Initiative*. Columbia Journal of Transnational Law, 25* (2), 347- 376.

Lemley, M. A, & Reese, R. A. (2004). Reducing Digital Copyright Infringement Without Restricting Innovation*. Stanford Law Review, 56*, 1345- 1354.

Lemley, M. A. (1997). The Economics of Improvement in Intellectual Property Law*. Texas Law Review, 75*, 989- 1084.

Levin, R. C. (1982). The semiconductor industry. In R. R. Nelson (Ed.), *Government and technical progress: A cross-industry analysis* (pp. 9-100). New York: Pergamon Press.

Levin, R. C., Klevorick, A. K., Nelson R. R., & Winter S. (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity*, *18* (3), 783- 832.

Lewis, T. G. (1995). Comment: Semiconductor Chip Process Protection. *Houston Law Review, 32,* 555.

Lojek, B. (2007). History of Semiconductor Engineering. Berlin: Springer.

Ludlow, T. (2014). Sign of the Times: Trends in Technology IP Licensing. *Intellectual Asset Management, 66,* 31-38.

Lukasiak, L., & Jakubowski, A. (2010). History of Semiconductors. *Journal of Telecommunications and Information Technology, (1)*, 3- 9.

Macher, J. T., Mowery, D. C., & Di Minin, A. (2008). Semiconductors. In J. T. Macher & D. C. Mowery (Eds.), *Innovation in global industries: U.S. firms competing in a new world* (pp.101-140). Washington, D.C: National Academies Press.

Malerba, F. (1985). *The semiconductor business: The economics of rapid growth and decline*. London: F. Pinter.

Manners, D. (2010). 50 Years of the UK Semiconductor Industry. *Electronics Weekly*. Retrieved March 17, 2015, from http://www.electronicsweekly.com/news/business/50-years-of-the-uk-semiconductor-industry-2010-09/>

Mansfield, E., Schwartz, M. & Wagner, S. (1981). Imitation Costs and Patents: An Empirical study. *The Economic Journal, 91* (364), 907-918.

Markoff, J. (2003). An inventor of the transistor has his moment. *New York Times*. Retrieved March 17, 2015, from http://www.nytimes.com/2003/02/24/business/a-parallel-inventor-of-the-transistor-has-his-moment.html?pagewanted=all

Mason, M. (1992). *American Multinationals in Japan: The Political Economy of Japanese Capital Controls 1899-1980*. Cambridge, Mass: Council on East Asian Studies, Harvard University.

McHugh, K. S. (1949). Bell System Patents and Patent Licensing. *Bell Telephone Magazine* 1-4.

Merges, R. P., and Nelson, R. R. (1990). On the Complex Economics of Patent Scope. *Columbia Law Review, 90,* 839.

Misa, T. J. (1985). Military Needs, Commercial Realities, and the Development of the Transistor, 1948-1958. In M. R. Smith (Ed.), *Military Enterprise and Technological Change: Perspectives on the American Experience* (pp. 256-264). Cambridge, Mass: MIT Press.

Miwa, Y., & Ramseyer, J. M. (2001). The Fable of the Keiretsu. *Harvard Law School Discussion Paper No. 316.*

Morgan, D. (1983). Battling to Innovate and Emulate: Intel versus Nippon Electric. *Washington Post*. Retrieved March 17, 2015, from http://www.washingtonpost.com/archive/politics/1983/05/02/battling-to-innovate-and-emulate-intel-vs-nippon-electric/058f705a-0c62-4fb6-aebe-e2beddd80c09/

Morris, P. R. (1990). *A history of the world semiconductor industry*. London: P. Peregrinus on behalf of the Institution of Electrical Engineers.

Morton, D. & Saby, J. (2000). *Electrical Engineer, An Oral History Conducted by David Morton.* IEEE History Center, New Brunswick.

Motohashi, K. (2008). Licensing or not licensing? An empirical analysis of the strategic use of patents by Japanese firms. *Research Policy*, *37* (9), 1548- 1555.

Mowery, D. C. (1994). *Science and technology policy in interdependent economies*. Boston: Kluwer Academic Publishers.

Mowery, D. C. (2015). “Breakthrough innovations” in aircraft and the IP system, 1900-1975. *WIPO Economic Research Working Paper* No. 25.

Nakagawa, Y. (1985). *Semiconductor development in Japan*. Tokyo: Diamond Publishing.

Nishizawa, J., & Ouchi, A. (1993). *Nihon no handotai kaihatsu (Semiconductor Development in Japan).* Tokyo: The Industrial Research Association.

OECD (1968). *Gaps in Technology – Electronics Components*. Paris: OECD Publishing.

OECD (2004). *The economic impact of ICT: Measurement, evidence and implications.* Paris: OECD Publishing.

OECD (2008). *OECD Information Technology Outlook.* Paris: OECD Publishing.

OECD (2015). *The future of productivity*. Paris: OECD Publishing.

Okimoto, D. I., Sugano, T., & Weinstein, F. B. (1984). Competitive Edge: The Semiconductor Industry in the U.S. and Japan. Stanford, Calif: Stanford University Press.

Okimoto, D.I. (1989). *Between MITI and the Market: Japanese Industrial Policy for High Technology.* Stanford, Calif: Stanford University Press.

Palomeras, N. (2004). *Markets for Inventors: Examining Mobility Patterns of Engineers in the Semiconductor Industry*. Retrieved March 17, 2015, from http://ssrn.com/abstract=875284

Pilat, D., & Wölfl, A. (2004). ICT production and ICT use: What role in aggregate productivity growth?. In OECD, *The economic impact of ICT: measurement, evidence and implications* (pp. 85–104). Paris: OECD Publishing.

PwC (2014). China's impact on the semiconductor industry. New York: Pricewaterhouse-Coopers.

Radomsky, L. (2000). Sixteen Years after the Passage of the U.S. Semiconductor Chip Protection Act: Is International Protection Working. *Berkeley Technology Law Journal, 15*, 1049.

Raskind, L. J. (1985). Reverse Engineering, Unfair Competition, and Fair Use. *Minnesota Law Review, 70*, 385- 415.

Rauch, J. G. (1993). The Realities of Our Times: The Semiconductor Chip Protection Act of 1984 and the Evolution of the Semiconductor Industry. *Fordham Intellectual Property, Media and Entertainment Law Journal*, *3* (2): 403- 407.

Riordan, M. & Hoddeson, L. (1997). Crystal Fire: The birth of the Information Age. New York: Norton.

Riordan, M. (2005). How Europe Missed The Transistor. *IEEE Spectrum*, *42* (11), 52 -57.

Risberg, R. L. (1990). Five Years Without Infringement Litigation Under The Semiconductor Chip Protection Act: Unmasking the Specter of Chip Piracy in an Era of Diverse and Incompatible Technologies*. Wisconsin Law Review, 1* 241- 277.

Roin*,* B. N. (2014). The Case for Tailoring Patent Awards Based on the Time-to-Market of Inventions*. UCLA Law Review, 61*, 36-37.

Rose, S. A. (2012). Semiconductor Chips, Genes and Stem Cells: New Wine for New Bottles? *American Journal of Law & Medicine, 38*, 113-57.

Saxena, A. N (2009). *Invention of Integrated Circuits: Untold Important Facts*. Hackensack, N.J: World Scientific.

Schmid, M., Ziener, D. and Teich, J. (n.d.). Netlist-Level IP Protection by Watermarking for LUT-Based FPGAs. Retrieved March 17, 2015, from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.161.3876

Schweyer, F. (2012). Die rechtliche Bewertung des Reverse Engineering in Deutschland und den USA. Tübingen: Mohr Siebeck.

SEMATECH (1998). *Memorandum of Understanding*. Retrieved March 17, 2015, from http://www.dod.gov/pubs/foi/Reading_Room/DARPA/10-F-0709_Memorandum_of_Understanding_SEMATECH.pdf

Semiconductor History Museum of Japan (2011). *Trends in the Semiconductor Industry*. Retrieved March 17, 2015, from http://www.shmj.or.jp/english/trends.html

Shapiro, C. (2000). Navigating the patent thicket: Cross licenses, patent pools and standard setting. In A. Jaffe, J. Lerner, & S. Stern (Eds.), *Innovation Policy and the Economy Vol. 1* (pp. 119-150). Cambridge, Mass.: MIT Press.

Shapiro, C. (2003). Technology Cross-Licensing Practices: FTC v. Intel. In J. E. Kwoka & L. J. White (Eds.), *The Antitrust Revolution* (pp. 350–369). Oxford: Oxford University Press.

Shockley, W. (1950). Electrons and Holes in Semiconductors: With Applications to Transistor Electronics. New York: Van Nostrand.

Skole, R. (1968). Government Electronic: Federal Outlets Tough for Foreigners*. Electronics*, *41*: 119- 124.

Smits, F.M. (1985). *A history of engineering and science in the Bell system. Electronics technology (1925-1975)*. Indianapolis: AT&T Bell Laboratories.

Staehlein, A. (1997). Das Trips-Abkommen: Immaterialgüterrechte im Licht der Globalisierten Handelspolitik. Bern: Stämpfli.

Stern, R. H. (1985). Determining Liability for Infringement of Mask Work. Rights Under the Semiconductor Chip Protection Act. 70 *Minnesota Law Review* 271.

Stern, R. H. (1986). “The Semiconductor Chip Protection Act of 1984: The International Comity of Industrial Property”. *Berkeley Journal of International Law*, 3(2): 273-310.

Stim, R. (2012). *Patent, Copyright and Trademark: An IP Desk Reference*. Berkeley, CA: Nolo Press.

Stiroh, K.J. (2002). Information technology and the U.S. productivity revival: What do the industry data say?*. American Economic Review*, *92*, 1559– 1576.

Terman, L., & Lanzerotti, M. Y. (2006). The Technical Impact of Moore's Law. *IEEE Solid-State Circuits Society Newsletter*, No. 3, Vol. 20.

Tilton, J. E. (1971), *International Diffusion of Technology: The Case of Semiconductors*. Washington D.C.: Brookings.

Tuomi, I. (2009). *The Future of Semiconductor Intellectual Property Architectural Blocks in Europe.* JRC Scientific and Technical Report. Retrieved March 17, 2015, from http://ftp.jrc.es/EURdoc/JRC52422.pdf

U.S. Copyright Office (1997). Report on Legal Protection for Databases. Retrieved March 17, 2015, from http://www.copyright.gov/reports/dbase.html

Uenohara, M., Sugano, T., Linvill, J. G., & Weinstein, F. B. (1984). Background. In D. I. Okimoto, T. Sugano & F. B. Weinstein (Eds.), *Competitive Edge: The semiconductor industry in the U.S. and Japan* (pp. 14-15). Stanford, Calif: Stanford University Press.

Van Ark, B., & Inklaar, R. (2005). *Catching up or getting stuck? Europe's problems to exploit ICT's productivity potential*. Paper presented at the International Symposium on Productivity, Competitiveness and Globalisation, Paris.

Van Ark, B. (2014). *Productivity and digitalisation in Europe: Paving the road to faster growth*. The Conference Board and the Centre for Innovation Economics.

Van Dormael, A. (2009). Biographies: Herbert F. Mataré. *IEEE Annals of the History of Computing, 31* (3), 68- 73.

Van Dormael, A. (2012). *The Silicon Revolution*. CreateSpace Independent Publishing Platform.

Van Dormael, A. (n.d.). *The ‘’French’’ Transistor*. Retrieved March 17, 2015, from http://www.cdvandt.org/VanDormael.pdf

Volokh, E. (1988). The Semiconductor Industry and Foreign Competition. *Cato Policy Analysis No. 99.*

Von Hippel, E. (1982). Appropriability of innovation benefit as a predictor of the source of innovation. *Research Policy*, *11* (2), 95- 115.

Warren, C. A., McMillan, B. & Holbrook, B. D. (1978). Military Systems Engineering and Research. In M. D. Fagan (Ed.). *A History of Engineering and Science in the Bell System: National Service in War and Peace (1925-1975)* (pp. 617-48). New York: Bell Telephone Laboratories.

Watanabe, M. (1979). Electrical Communications Laboratories: Recent LSI Activities. *Japan Telecommunications Review,* pp. 3-8.

Wolf, S., & Tauber, R. N. (1986). *Silicon Processing for the VLSI Era, Volume 1: Process Technology*. Sunset Beach, Calif: Lattice Press.

Wolfson, J. A. (1993). Patent flooding in the Japanese Patent Office: Methods for reducing patent flooding and obtaining effective patent protection. *George Washington Journal of International Law and Economics*, *27*, 531- 563.

Woodson, W., & Safreno, D. C. (1985). The Semiconductor Chip Protection Act of 1984*. Santa Clara Computer & High Technology Law Journal, 1* (1), 7- 12.

WSTS (2015). WSTS *Semiconductor Market Forecast Spring 2015*. Retrieved July 9, 2015, from https://www.wsts.org/PRESS/PRESS-ARCHIVE/WSTS-Semiconductor-Market-Forecast-Spring-2015.

Cases

Brandir Int'l, Inc. v. Cascade Pac. Lumber Co., 834 F.2d 1142, 1143, 1148 (2d Cir. 1987).

Motorola, Inc. v. Fairchild Camera and Instrument Corp., 366 F. Supp. 1173 (D. Ariz. 1973).

Noyce v. Kilby, 416 F.2d 1391 (C.C.P.A. 1969).

U.S. v. Western Elec. Co., 1956 Trade Cas. (CCH) para. 68, 246 (D.N.J. Jan. 24, 1956).

Universal Furniture Int'l, Inc. v. Collezione Europa USA, Inc., 196 F. App'x 166, 171 (4th Cir. 2006).

ConWest Res., Inc. v. Playtime novelties, Inc., 84 U.S.P.Q.2d 101, 1023-24 (N.D. Cal. 2006).

International News Service v. Associated Press, 39 S. CT. 68 (1918).

Supreme Court: Kewanee Oil Co. v. Bicron Corp*.*, 94 S. CT. 1879 (1974).

Brooktree Corp. v. Advanced Micro Devices, Inc., 977 F.2d 155 (Fed. Cir. 1992),

Altera v. Clear Logic, Case Nos. 03-17323, 03-17334 (9th Cir. Sept. 15, 2005).

Avel Pty Limited v. Wells [1991] FCA 590, (1992) AIPC 90-846 (1991); 22 IPR 305; 105 ALR 635 (December 2, 1991).

Quanta Computer, Inc. v. LG Electronics., Inc., No. 06-937, 2008 U.S. LEXIS 4702 (U.S. June 9, 2008).

South Corp. v. United States*,* 690 F.2d 1368 (Fed. Cir. 1982).

Intergraph Corporation v. Intel Corporation, US Court of Appeal for the Federal Circuit, 98-1308, decided on November 5, 1999.

Annex

The study relies on a mapping of patents developed especially for the WIPR 2015 report. The mapping is based on the IPC and CPC symbol H01L, including all lower levels. The patent data for these mappings come from the WIPO Statistics Database and the EPO Worldwide Patent Statistical Database (PATSTAT, April 2015).

Key methodological elements underlying the mapping exercise include the following:

Unit of analysis

The main unit of analysis is the first filing of a given invention.[187] In consequence, the date of reference for patent counts is the date of first filing. For some historical records – for example, those older than 1930 for USPTO documents – the application date is missing. In such cases, the date of the earliest subsequent filing or the grant date of the first filing has been used. The origin of the invention is attributed to the first applicant of the first filing; whenever this information was missing an imputation strategy has been applied, as described further below.

The only departure from this approach occurs when analyzing the share of patent families requesting protection in each patent office. In this case, an extended patent family definition – known as the INPADOC patent family – has been used instead of the one relying on first filings. In addition, only patent families with at least one granted application have been considered for this analysis, and the date of reference is the earliest filing within the same extended family. The main rationale for using the extended patent family definition and imposing at least one granted patent within the family is to mitigate any underestimation issuing from complex subsequent filing structures, such as continuations and divisionals, and from small patent families of lower quality such as those filed in only one country and either rejected or withdrawn before examination.

Imputing country of origin

When information about the first applicant’s country of residence in the first filing was missing, the following sequence was adopted: (i) extract country information from the applicant’s address; (ii) extract country information from the applicant’s name (see further below); (iii) make use of the information from matched corporations (as described further below); (iv) rely on the most frequent first applicant’s country of residence within the same patent family (using the extended patent family definition); (v) rely on the most frequent first inventor’s country of residence within the same patent family (again, using the extended patent family definition); and (vi) for some remaining historical records, consider the IP office of first filing as a proxy for origin.

Cleaning applicant names and assigning applicant types

Applicants have been categorized in three broad categories: (a) *Companies*, which includes mostly private companies and corporations, but also state-owned companies; (b) *Academia and public sector*, which includes public and private universities (and their trustees and board of regents), public research organizations, and other government institutions such as ministries, state departments and related entities; (c) *Individuals*, which includes individual first applicants who may or not be affiliated with companies, academia or other entities. A further category, (d) *Not available*, includes all unclassified first applicants.

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[187] Mappings include data on utility models whenever available.

In order to assign broad type categories to each first applicant, a series of automated steps were performed to clean and harmonize applicant names. The results of this automated process were cross-checked manually – particularly for the top applicants of each type – prompting revision of the strategy and adjustment of parameters in several iterations.

The starting point was the original information about the first applicant's name from the first filing. When this name was missing, the most frequent first applicant's name within the same patent family using the extended definition was considered. This list of improved first applicants' names was automatically parsed in several iterations in order to: (i) harmonize case; (ii) remove symbols and other redundant information (such as stop words and acronyms); (iii) remove geographical references (used to improve information on applicants' country of residence); and (iv) obtain any valuable information on applicant names meeting criteria to be considered as (a) *companies* or (b) *academia and public sector* types.

Subsequently, a fuzzy string search was performed – using Stata's *matchit* command[188] – in order to detect alternative spellings and misspellings in applicant names, and the types were propagated accordingly. Finally, the category *individuals* was imputed only to remaining unclassified records when they either appeared as inventors in the same patent or were flagged as individuals in the WIPO Statistics Database for patent families containing a PCT application. Analysis of the unclassified records indicates that most of them have missing applicant names in PATSTAT. Most of these missing names refer to original patent documents not in Latin characters and without subsequent patent filings.

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[188] Available at the Statistical Software Components (SSC) archive and from the WIPO website.