Louvain School of Management

Key success factors in the semiconductor industry:

Comparative analysis of the US, European and Chinese semiconductor industries

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During the process of writing my thesis, I was lucky to be surrounded by inspiring people. This allowed me to be more confident with the knowledge I've gained, but also to be proud of the work I've accomplished.

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Acronyms and Abbreviations

ADAS	Advanced Driver-Assistance System
AI	Artificial Intelligence
AR/VR	Augmented Reality & Virtual Reality
ATP	Assemble, Test and Packaging
Bn	Billion
CAGR	Compound Annual Growth Rate
DARPA	Defense Advanced Research Projects Agency
DOE	Department of Energy
DRAM	Dynamic Random-Access Memory
ELG	Electronics Leaders Group
ERSO	Electronic Research Service Organization
ESIA	European Semiconductor Industry Association
EU	European Union
FDI	Foreign Direct Investment
FYP	Five Year Plan
GCTI	Global Talent Competitiveness Index
GDP	Growth Domestic Product
GDPR	General Data Protection Regulation
ICs	Integrated Circuits
ICT	Information and Communication Technology
IDM	Integrated Device Manufacturer
IP	Intellectual Property
IPCEI	Important Project of Common European Interest
IT	Information Technology
M&A	Merger and Acquisition
MCU	Microcontroller
MOFCOM	Ministry of Commerce
NAFTA	North American Free Trade Agreement
NIST	National Institute of Standards and Technology

OSCCA	The Office of State Commercial Cryptography Administration
R&D	Research and Development
RTO	Research and Technology Organization
SAE	Smart Anything Everywhere
SEI	Strategic Emerging Industries
SEM	Single European Market
SIA	Semiconductor Industry Association
SME	Small and Medium Enterprise
SMIC	Semiconductor Manufacturing International Corporation
TI	Texas Instrument
US	United States
USMCA	United States – Mexico – Canada Agreement
WSTS	World Semiconductor Trade Statistics
WTO	World Trade Organization
WWII	World War II

Introduction

International trade has increased over the years. Since 2000, world merchandising trade has risen by 1400% from US$1.35 trillion to US$19.051 trillion in 2019 (World Trade Organization, 2020). This high growth rate led to an intensification in international interactions between people all around the world sharing their knowledge, research and ideas. Nowadays, we can reach a multitude of nationalities and countries which, in return, fosters the creation of most products and innovations.

Across the years, the world progressively became interdependent. The global semiconductor industry is an excellent example to illustrate the rise of this phenomenon. Indeed, an average of 35 different countries oversee the manufacture of a semiconductor product, as it requires various set of skills and knowledge. It is safe to say that the semiconductor industry represents a global ecosystem. Moreover, the final product reaches the end consumer after crossing international borders approximately 70 times (Accenture, 2020).
With the increasing number of multinational companies in the sector, competition is fierce, and innovation has no limit (SIA, 2020a). The race to maximize profit and increase market share is greater than ever before which, consequently, makes the global value chain of semiconductor products more vulnerable (McKinsey, 2020). As seen with the covid-19 crisis, some electronic manufacturing firms located in China were idle during a period of time, further involving shortage problems for suppliers and end-consumers all around the world (Deloitte, 2020).

Given this context, I decided to focus my master's thesis on the semiconductor industry and try to define key characteristics a market should have that benefit the development of semiconductor companies. Indeed, semiconductor firms evolve in different environments linked to their home country or countries they operate. They face thus different industrial policies and governmental aids such as subsidies, national or regional programs aiming to develop the semiconductor industry, and incentives helping semiconductor companies. National and regional governments and institutions provide also distinct levels of protection for their semiconductor industry. Moreover, markets where semiconductor companies are evolving are heterogenous. Therefore, semiconductor firms face different demands from countries or regions, levels of skilled workforce, and labour costs.

In order to point out and develop the most efficient success factors that benefit a semiconductor company, I will proceed to a comparative analysis of three different economic units. Therefore, I focus my master's thesis on the semiconductor industries of the United States, the European Union and China. I decided to include those three regions in my research because I wanted to provide an analysis of semiconductor markets that are at different development stages. Indeed, the US semiconductor industry represents, since the start of the industry's history, the biggest market share in the world (Statista, 2020f). Top semiconductor leaders come mostly from the US and despite the increasing competition, they are constantly innovating (SIA, 2020a). Then, the EU semiconductor industry had a promising future, but European companies failed to become worldwide leaders. Nevertheless, they are now trying to catch up the level of top players in the industry (ESIA, 2019). Finally, Chinese companies arrived later in the global semiconductor market, but that will not stop them to gain market shares. In the beginning of the 21st, the Chinese government decided to develop ruthless strategies aiming to outweigh international companies in the worldwide semiconductor industry (Sauvage, 2019).

Within the framework of my master's thesis, I decided not to study other countries such as Taiwan, South Korea and Japan even if they are in the top 5 of leading countries in the semiconductor industry in terms of market shares (Statista, 2020f). Indeed, in order to provide a comprehensive analysis, I had to restrict the number of different economic regions and choose to take the most opposed in terms of positions in the worldwide semiconductor industry, cultural values and business environments. However, it would be very interesting to analyze it in future research.

As the semiconductor industry is one of the most disputed points in the current geopolitical tensions between the United States and China, this subject is prone to many distorted and subjective information. Having this in mind, I made a deep literature review on the subject and tried to find information written by authors coming from different countries in order to confront them. Also, throughout my research, I related heavily on macroeconomics indicators and factual data. This allowed me to avoid biases as much as possible and to not base my thesis on personal opinions or judgements. This type of data is quite sensitive to governments which increases the difficulty to find reliable information. I had thus to build a proper argumentation based on available data.

This master's thesis is composed of three parts. In the first one, based on literature review, I will provide a state of affairs of the global semiconductor industry and its international supply chain. Also, I added a historical background of the industry in order to better understand the worldwide context where semiconductor companies coming from the United States, the European Union and China have born and evolved. Following this, I will provide a summary of the current key players in the industry and to which degree they are impacted by the increasing geopolitical tensions between the US and China.

In the second part, I will develop some key characteristics for the semiconductor industry of the chosen regions and check whether they benefit or not the companies. I will try to be as complete as possible while also focusing only on the most relevant aspects. Further, I will provide a comparative analysis on the importance and effectiveness of each factor for the development of the semiconductor industry in the three regions.

In the last part, I will provide key recommendations that are most appropriate to the three regions environment and needs. Those recommendations aim at improving the current position of each semiconductor industry.
Finally, the conclusion of my master's thesis will highlight the most efficient characteristics business environments should have in order for semiconductor companies to grow and thrive in their market. I will also provide limits of my research and ideas for further analysis.

PART 1 : The semiconductor industry

1. The global semiconductor market

Semiconductors are defined as:

> An essential component of electronic devices, enabling advances in communications, computing, healthcare, military systems, transportation, clean energy, and countless other applications. Semiconductors, sometimes referred to as integrated circuits (ICs) or microchips, are made from pure elements, typically silicon or germanium, or compounds such as gallium arsenide (SIA, 2020d).

Semiconductor products have an important place in our life as they are used in daily objects such as smartphones, radios, TVs, computers, video games or even advanced medical diagnostic equipment (SIA, 2020d).

The semiconductor industry has been well implemented in the market for several years. The market of traditional products such as Integrated Circuits (ICs) is mature and most segments are dominated by a few large and international firms. Due to economies of scale sought out from those firms, competition is fierce and barriers to entry are high (VerWey, 2019). However, the semiconductor market will continue to grow as new emerging sectors such as Artificial Intelligence (AI), 5G and the automobile industry are being developed.
These new sectors will increase competition for market share between semiconductor firms while startups and new entrants from emerging economies will also enter the market. Companies in the semiconductor industry will have to diversify their operations in order to capture the most value across the value chain (SIA, 2020a).

The semiconductor industry is globally shared among 6 countries. In 2019, the United States dominated the market with about 47% of market share. Followed by South Korea (19%), Japan (10%), the European Union (10%), Taiwan (6%) and China (5%) (Figure 1) (Statista, 2020f).

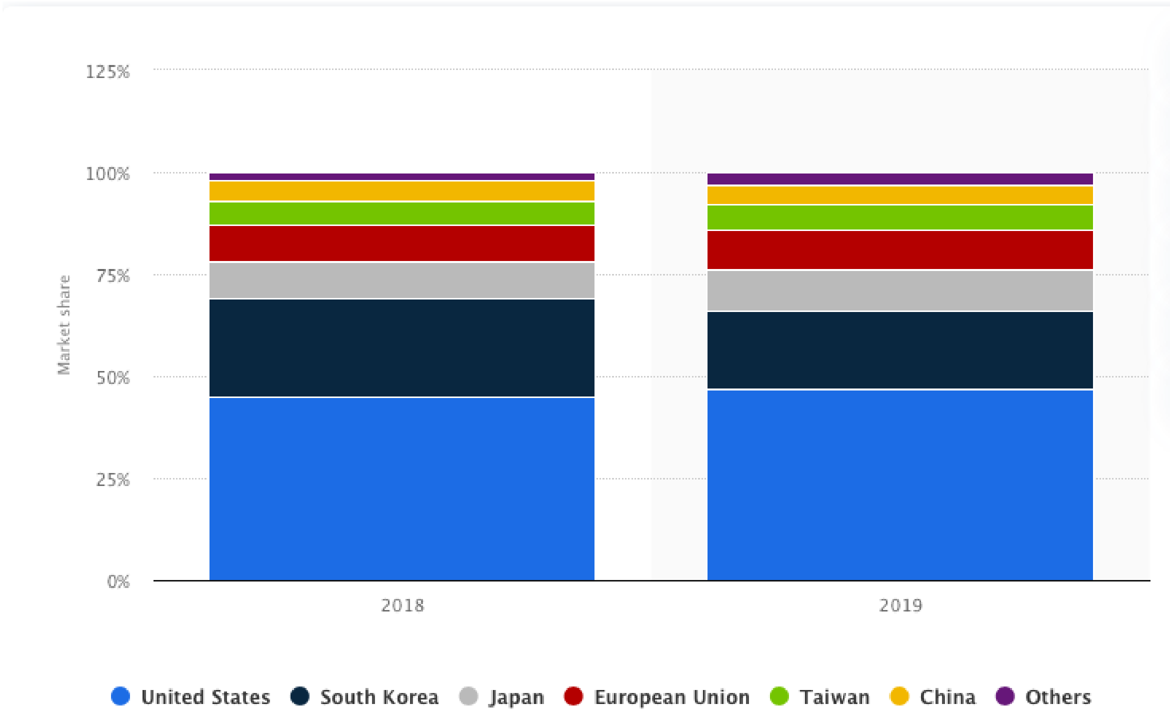

Figure 1: The market share in percent of the global semiconductor industry per country in 2018 and 2019 (Statista, 2020f).

After recorded sales of US$468.8 bn in 2018, global sales suffered from a sharp decrease of 12% to US$412.1 bn in 2019 due to the cyclicality of the memory market[1] (Figure 2). The World Semiconductor Trade Statistics (WSTS) organization forecasted an increase of global sales to US$426 bn for 2020. In 2021, WSTS forecasts global sales to reach US$452 bn (SIA, 2020a).

[1] The cyclicality of the memory market is due to fluctuations in capacity and in capital spending from semiconductor companies. This leads to a weaker demand and a fall of prices of memory products. With its US$99.4 bn in revenue in 2018, the worldwide DRAM market is the largest single product category in the semiconductor industry followed by NAND flash with US$59.4 bn. (Jorgensen, 2019).

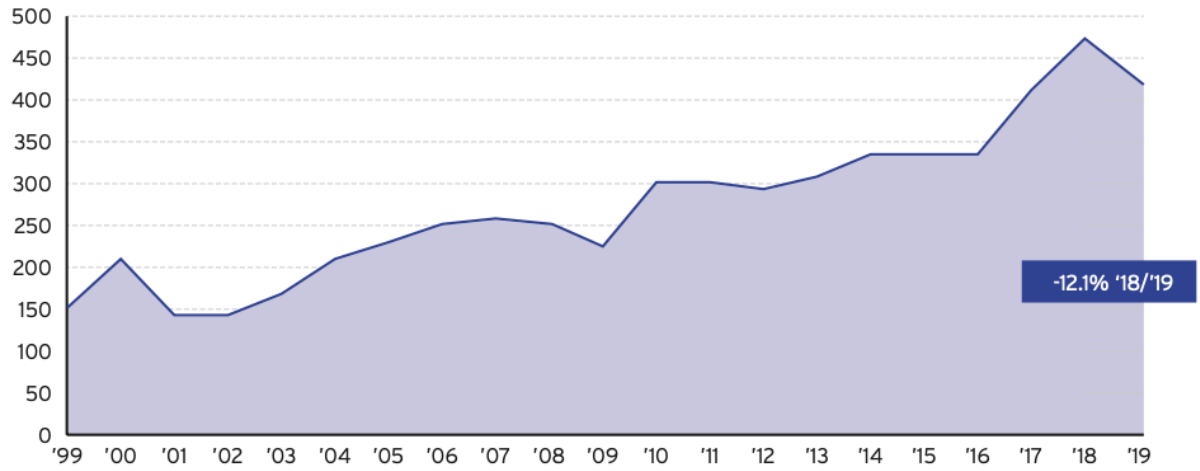

Figure 2: Global semiconductor sales in US$ bn (vertical axis) from 1999 until 2019 (SIA, 2020a).

1.1. The semiconductor demand

Semiconductor chips are used in a wide range of products and technologies, such as smartphones, computers, cars, industrial equipment but also AI, wireless technology, cybersecurity, edge computing, sensors and power management. Those innovations need to transfer, store and analyze a big amount of data which is possible through the use of semiconductor products (European Commission, 2018).

The semiconductor industry is a market in which products continuously improve. By consequence, it also increases the quality of the end-user products using those semiconductors. As semiconductor products become essential in the production chain, the demand increases, and so does the price. This increase in revenue allows companies to make larger R&D investments and develop more advanced semiconductors. This is known as the innovation cycle which allows the digital economy to grow (SIA, 2020a).

Globally, semiconductor components for automotive and industrial electronics are the most demanding and are thus growing at the highest rate (Figure 3). This is due to the electrification and automation of vehicles, digitalization of industry and electrical power grids (SIA, 2018).

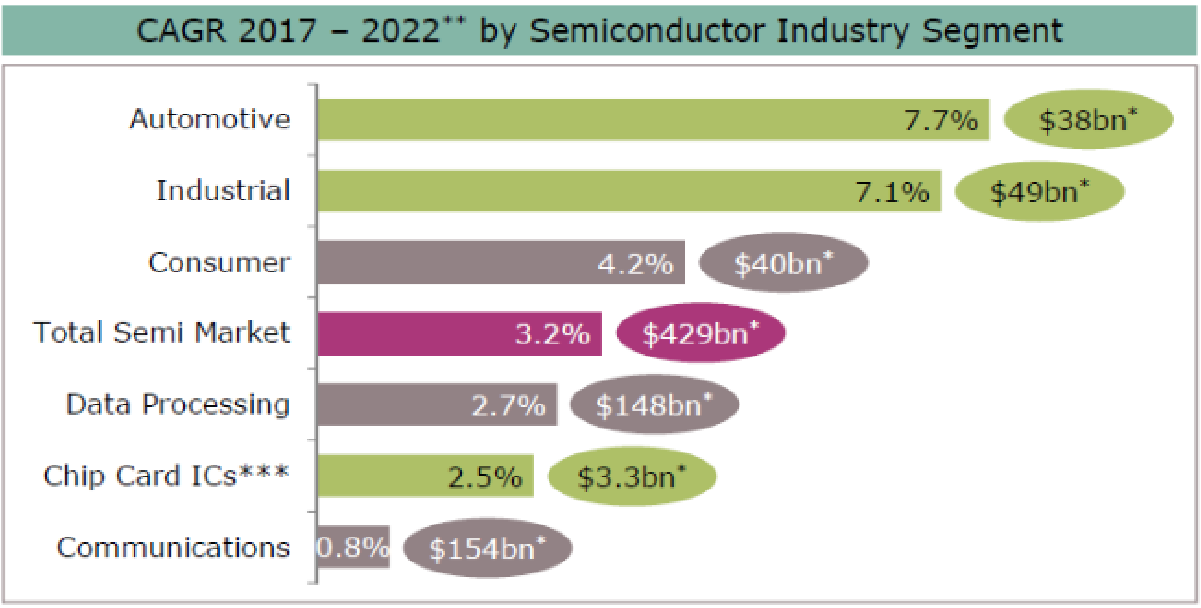

Figure 3: Forecasted compound annual growth rate (CAGR) by semiconductor industry segment from 2017 until 2022 (European Commission, 2018).

1.2. Emerging technologies

As previously said, new technologies are being developed and will require a high level of semiconductor products.

Regarding the automotive sector, the recent adoption of safety-related electronics systems induces the use of various semiconductor devices, such as microcontrollers, sensors and memories that are used to make state of the art cars. Advanced driver-assistance systems (ADAS) will have the highest growth further inducing an increase in the demand for ICs (Integrated circuits), MCUs (Microcontroller units) and sensors (Chen & al., 2019). Currently, semiconductor products required per vehicle are five times higher for a full automation system than a hybrid one (Pwc, 2019).

AI technology is prospering in various sectors and increasing the demand for AI semiconductor devices, especially at the ICs level. According to a McKinsey survey (2020), the demand for AI-related chips will account for 20% of the semiconductor demand while generating US$67 bn in revenue before 2025.
The cloud is especially the biggest market in the AI sector as it represents the data centers enhancing the efficiency and reducing operational cost of companies (Chen & al., 2019).

The introduction of 5G will maintain a 2.2% growth rate in the communication market which accounts for 80% of the demand for semiconductor products (Pwc, 2019). As the 5G is entering our market, 5G semiconductor revenue is forecasted to increase from nearly zero in 2018 until US$31.5 bn in 2023. The increasing volume of global data will lead to an increasing demand for ICs.

1.3. Complex global value chain

As the global semiconductor industry reaches the limits of Moore's Law[2], the total expenses associated with manufacturing chips can only be borne by the largest firms in the world (VerWey, 2019). Those expenses are represented by R&D investments required to upgrade semiconductor products but also to cover the cost of building leading-edge fabs and to develop state-of-the-art process technologies. According to a Global Innovation 1000 Study made by Chwalik, Goehle and Jaruzelski (2018), R&D investments made in 2018 from worldwide semiconductor companies in percentage of their revenue was about 20.9%, representing US$97.97 bn, compared to 5.7% in the automobiles and components industry. This percentage has increased throughout the years due to the rise of new technologies on the market and the fixed costs linked to it. Already in 2012, only Intel, Samsung, and Texas Instrument, the three global leading firms in the semiconductor industry, were able to afford the cost of manufacturing 22 nanometers nodes (McKinsey, 2011).

The increasing cost in this industry since the past few years has forced most companies to stop manufacturing the whole product from the beginning until the end in order to specialize in only one or few segments of the value chain. This process is called the "fab-lite" strategy which implies the decision of companies to outsource a large part of their chip production (Design & Reuse, 2014). By narrowing their strategic product focus, companies don't require expensive fabs or wafer processes anymore. This led to a net decrease of capital expenditure from 27% to 20% of revenue in ten-year time (Figure 4) (McKinsey, 2011).

[2] The Moore's Law refers to the observation of Gordon Moore in 1965 saying that the number of transistors on a microchip doubles every two years while the cost of computers halves. This means that the speed and capability of our computers will increase while we are paying less. However, today the doubling of installed transistors on silicon chips is faster than every two years (Investopedia, 2020).

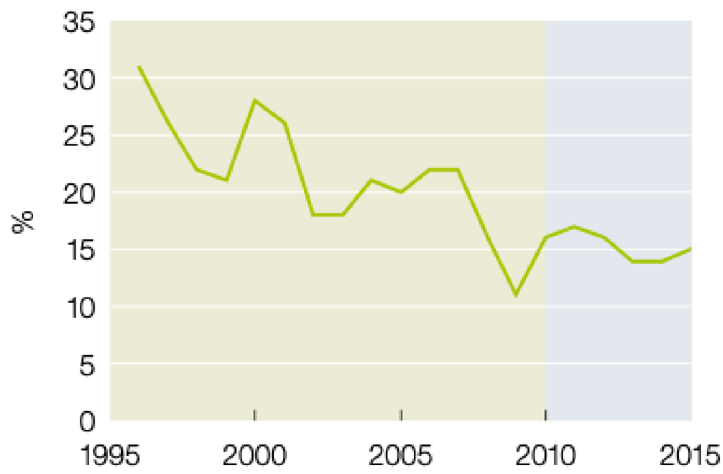

Figure 4: The percentage of capital expenditure to companies' revenue in the semiconductor industry from 1995 until 2015 (forecasted from 2010) (McKinsey, 2011).

The high specialization degree in the industry implies that semiconductor companies and other related businesses have a high level of interdependence. Most firms that choose to not produce everything at home, source several components from all around the world. This implies a complex global value chain that is vulnerable to many disruptions (McKinsey, 2020).

Semiconductor firms are mostly organized around three activities which are the main stages of semiconductor production: Design, Manufacturing, and Assembly, Test and Packaging (ATP). Companies focused on the design are called "fabless" firms and those focused on the manufacturing part are referred to as "foundries". Firms that are not specialized in any kind of activities and produce everything internally are called Integrated Device Manufacturers (IDMs) (Figure 5) (SIA, 2020a).
However, even with the fab-lite strategy, foundries still have capital-intensive requirements. Companies need to reach large production volumes and high production yields in order to spread their large capital expenditure and obtain economies of scale (Sauvage, 2019). This induces a high level of consolidation among semiconductor companies. In 2017, the world's top five semiconductor suppliers accounted for 43% of total chip sales (Rhines, 2019).

Integrated device manufacturer (IDM) model		
Intel, Micron, Samsung, Texas Instruments		
Fabless-foundry model		
Design (fabless)	**Manufacturing (foundries)**	**Assembly, test, and packaging (ATP)**
AMD, Broadcom, MediaTek, HiSilicon, Qualcomm	GlobalFoundries, SMIC, TSMC, UMC	Amkor, ASE, ChipPAC, JCET, J-Devices, Power-tech, SPIL

Figure 5: Operations models in the semiconductor industry and its leading firms (VerWey, 2019).

The semiconductor industry is a global ecosystem requiring materials, manufacturing processes and talented people from all around the world. According to research made by Accenture (2020), 25 countries are involved in the manufacturing of a semiconductor product. Before it gets to the end consumer, the product could approximately cross international borders 70 times.

2. Historical background of the semiconductor industry

2.1. The US precursors

The semiconductor industry began in 1952 with the presentation of an electronic transistor created by AT&T, a US company. This was led by an increasing US demand for semiconductor products for military purposes (Chandler, 2005).

In the late 60s, the market was shared amongst three US companies: Texas Instrument, Fairchild and Motorola. As they began to produce products for commercial purposes, they increased their sales and together they maintained 70% of the market.

Texas Instrument was the most powerful of the three companies. During the 60s, TI made large investments in production and manufacturing facilities at home which allowed it to expand by building plants and increasing its international network. In 1965, TI was already operating fifteen plants in ten different countries. Some in Europe in order to be closer from customers and others in Asia and Latin America to benefit from cheap labour. In 1968, TI was one of the largest producers of semiconductors in Britain, France and Germany. Those international expansions were made generally through direct investments by wholly owned subsidiaries (Chandler, 2005).

Motorola had a similar strategy but slower and less aggressive compared to TI. By 1970, Motorola was also present in several countries in Europe, Latin America and Asia. In 1972, Motorola was the second world leader in the semiconductor industry, just after TI (Chandler, 2005).

During the 70s Intel made its place in the sector by commercializing the first microprocessor. However due to the large economies of scale acquired by TI and Motorola already in place, both companies quickly surpassed Intel in terms of market share for the production of microprocessors (Chandler, 2005).

Through the increasing global demand for microprocessors and personal computers, the semiconductor industry in the U.S. developed very well. In the late 70s, US firms represented 60% of the global semiconductor market share and the worldwide sales in the sector rose from US$ 4.4 bn to US$141 bn from 1975 until 1995. The five major competitors in the US industry were TI, Motorola, Intel, Advanced Micro Devices and National Semiconductor (National Research Council, 2002).

2.2. European and Japanese prime movers

The European semiconductor industry began to develop after WWII with the Dutch company Philips, which was the main consumer electronics learning base in Europe. The German company Siemens arrived on the market a few years later when it received the AT&T's Western Electric license in 1952. Because they were only two on the European market, Philips concentrated on the new electronic technology in the consumer market and Siemens focused on the market for telecommunication, industrial products, and new data processing computers. Several years later, Thomson-Brandt, a French semiconductor company joined the market. However, due to insufficient R&D investments, the company was forced to stop its activities in 1995. By 1960, Philips accounted for half of the semiconductor sales in England, France and Germany. Through several acquisitions, Philips has gained a global market share of 10% in 1983 (Chandler, 2005).

German semiconductor companies have always adopted a different approach from its neighbors in the Netherlands or France. Siemens, the leading company in the country, followed a “follower-imitator” strategy and developed its technological capabilities by working with leading companies in the market.

In the beginning of the 80s, Japanese firms such as NEC, Toshiba, and Hitachi entered the semiconductor market as well. They developed themselves until the beginning of the 90s and dominated the market alongside with US firms. Six Japanese companies were among the top ten semiconductor leaders, the four others were from the US (Chandler, 2005).

US, Japanese and German firms were the first movers, followed by several other European companies such as Swedish and Swiss businesses (Chandler, 2005). At that time the market was vertically integrated, and companies were large. The emerging fabless-foundry model led to an increase in the number of small and mid-sized chip firms. Since then, the high cost of competition in the market has induced an increasing level of consolidations between firms (McGrath, 2018).

This caused huge losses to European semiconductor companies and especially to Siemens that had no choice than to enter in joint venture with Fujitsu, a Japanese company (Chandler, 2005).

The number of manufacturing facilities located in Europe in the 90s reduced radically. Old fabs closed and replaced by new ones in other locations where labour costs were lower. The mid-term consequences of offshoring and outsourcing induced losses of human resources, industrial know-how, and key equipment which were needed to build new factories. This weakened the European semiconductor industry during the years. It placed the European market in a weaker position in regard to other producing countries (Coulon, Olliver, Dubois, Saint-Martin & Vodovar, 2020).

During the 90s, the number of Japanese companies present in the market also decreased, from a total of six companies in the top ten of the worldwide semiconductor companies in 1990 to only three by 2000. This decrease was caused by some wrong decisions made by the Japanese government and companies. At that time, Japanese companies focused on the consumer electronics segment that had boomed in the late 90s. However, the US had already a leader position in this section and Intel was the market leader.

Also, the emergence of the foundry-fabless model at the end of the 20th century induced many disruptions in the market already in place. As most of Japanese companies in the sector were IDMs, they were highly affected by this increasing cost of production.
However, today Japan is the leader in the segment of semiconductor equipment and materials. An estimation of Semiconductor Equipment and Materials International confirmed that Japanese companies supply about 50% of the materials and 35% of the new equipment used globally (Tayal, 2015). In 2019, only two Japanese chipmakers have remained in the top 15 semiconductor firms worldwide: Kioxia (formerly Toshiba) and Sony (Congressional Research Service, 2020).

2.3. The rising of the Asian market

In the years between 1980 and 2000, Asian countries began to develop their own semiconductor industry as well. The main strategy of Asian countries in order to catch up with global leaders was to make a wide range of M&As and joint ventures. Being precursors among Asian countries, the Japanese firms have utilized this technique with US companies and forced them to enter joint ventures to access the Japanese market.

South Korea, while entering the market in the 80s, have used their large homegrown conglomerates to develop its semiconductor industry. Using their access to capital markets, South Korean companies have found a place in the dynamic random-access memory (DRAM) market. The heavy R&D investments strategy and the licensing of the US technology enabled Korean firms, such as Samsung and SK Hynix to rapidly catch up with large global semiconductor companies (Sauvage, 2019).

Taiwan also entered the market at the same time. As most of Asian companies, Taiwanese companies used foreign technologies already developed by the US, European and Japanese firms to reach the international technological level of the semiconductor industry. The current position of large Taiwanese firms such as TSMC, UMC and Vanguard International Semiconductor is largely due to the public research institute ERSO (Electronic Research Service Organization) and its efforts to acquire foreign companies and develop R&D investments. Also, the foundry model developed by TSMC allowed it to increase its international exposure and rapidly catch up with foreign companies (Sauvage, 2019).

Although those two countries had approximately the same strategy and arrived on the market during the same period, the Taiwanese market is differentiating itself from the Korean one as Taiwanese firms were able to develop different partnerships with foreign companies. It fosters Taiwanese entrepreneurs to build their own companies and become major actors in the semiconductor industry. Taiwanese semiconductor industry represents thus an interdependent network of specialized firms. By contrast, South Korean large conglomerates have taken the role of IDMs in the semiconductor industry throughout the years (Sauvage, 2019).

2.4. The catch-up strategy of China

Although the first Chinese semiconductor firm started to make its first transistor in 1956, the Chinese semiconductor industry truly developed between the late 90s and the beginning of this century. Before that, the Chinese government tried to implement several plans and strategies, such as the implementation of the "Computer and Large Scale IC Group" to foster the industry. However, China didn't have the required resources to develop in the sector. Also, the Chinese semiconductor industry was split into two categories: The R&D part on one side and the manufacturing part on the other side. Those two sub-sections were rarely co-located which made technological development more difficult (VerWey, 2019).

Throughout the 90s, while most fabs located in North America and Europe were closing and new ones were being built in Asia, the Chinese government implemented a joint venture strategy with foreign high-tech companies. Few Chinese firms succeeded to partner with NEC (Japan), Nortel (Canada), Philips (the Netherlands) and ITT (Belgium). It allowed the Chinese semiconductor companies to focus on DRAM chips and enter into production processes (VerWey, 2019).

By joining the WTO in December 2001, trade taxes between China and other countries were lowered. As the semiconductors and electronic components were among the fast-growing sectors in terms of shipment of goods, mostly between the US and China, leading international firms found it attractive and easier to establish local operators in China (Blustein, 2019).

In the beginning of the 2000s, the Chinese semiconductor market grew rapidly. The Chinese consumption of semiconductor products in 2005 was 31% more than the previous year. However, most of the Chinese demand for semiconductor products were coming from foreign semiconductor companies located in China. Indeed, at that time, no Chinese-owned companies in the semiconductor industry were in the top 70 chip suppliers. Chinese companies already existent didn't have a sufficient growth rate in order to compete with international firms (Pausa, 2007).

The Chinese government understood the growing importance of the semiconductor industry and the benefits that it could have on its economy. Therefore it decided to target the sector as one of its key industries in the 10th, 11th and 12th Five Year Plan from 2001 until 2015. The government put a focus on improving R&D capabilities for advanced technology and advanced capacity. It also increased governmental support for firms in the sector such as tax incentive policies, tariff exemptions and loans from state-owned banks (Chai, 2011). The Chinese government decided to spend about US$360 bn (CNY ¥.4 trillion) for science and technology over the 2006-2012 period which was planned by the "Medium and Long-term Plan for science and technology 2006-2020". This plan fostered 16 Chinese sectors including "core electronic components" and "advanced IC manufacturing". A second round of R&D funding into the Chinese semiconductor industry was also made in 2010 from the government as being part of the "Strategic Emerging Industries (SEI)" initiatives (Sauvage, 2019). Through the means of Chinese governmental aids, Semiconductor Manufacturing International Corporation (SMIC), also known as the biggest Chinese semiconductor company, was able to develop by partnering with foreign firms and acquiring talented engineers (VerWey, 2019).

The semiconductor sales of Chinese companies grew by 29.5% between 2001 and 2011. Furthermore, the market share grew from 1.9% in 2001, to 9.8% in 2011. However, the domestic production from Chinese-owned companies was still insufficient to balance the demand and the amount of imports of semiconductor products remained high. At that time the top 10 semiconductor suppliers of the Chinese market were all foreign firms such as Intel, Samsung, Toshiba, TI, SK Hynix, … (Kong, Ramu & Zhang, 2015).

In order to improve the position of its semiconductor companies, the Chinese government elaborated three strategic programs as part of the 13th Five Year Plan in 2015. They cover goals and guidelines for the Chinese semiconductor industry: “The Guidelines to Promote a National Integrated Circuit Industry”, “Made in China 2025” and “The Made in China 2025 Technical Area Roadmap”.

The objective of those plans is to gradually replace foreign technology that Chinese companies are currently dependent on with local technology (Figure 6). In order to achieve this, Chinese investors have planned to increase the mergers and acquisitions of international firms in the sector. Those investments aim at gaining foreign cutting-edge technologies and permit large-scale technology transfers from foreign companies. As Chinese companies want to gain control over most profitable segments of the global semiconductor supply chain in the long term, the government uses several mechanisms to facilitate the transfer of technology. For example, technology spillovers from inward-direct investment from foreign companies into China, cooperation with foreign enterprises, the foreign recruitment of the R&D and technology staff and the construction of R&D centers in leading countries (Conrad, Ives, Meissner, Wubbeke & Zenglein, 2016).

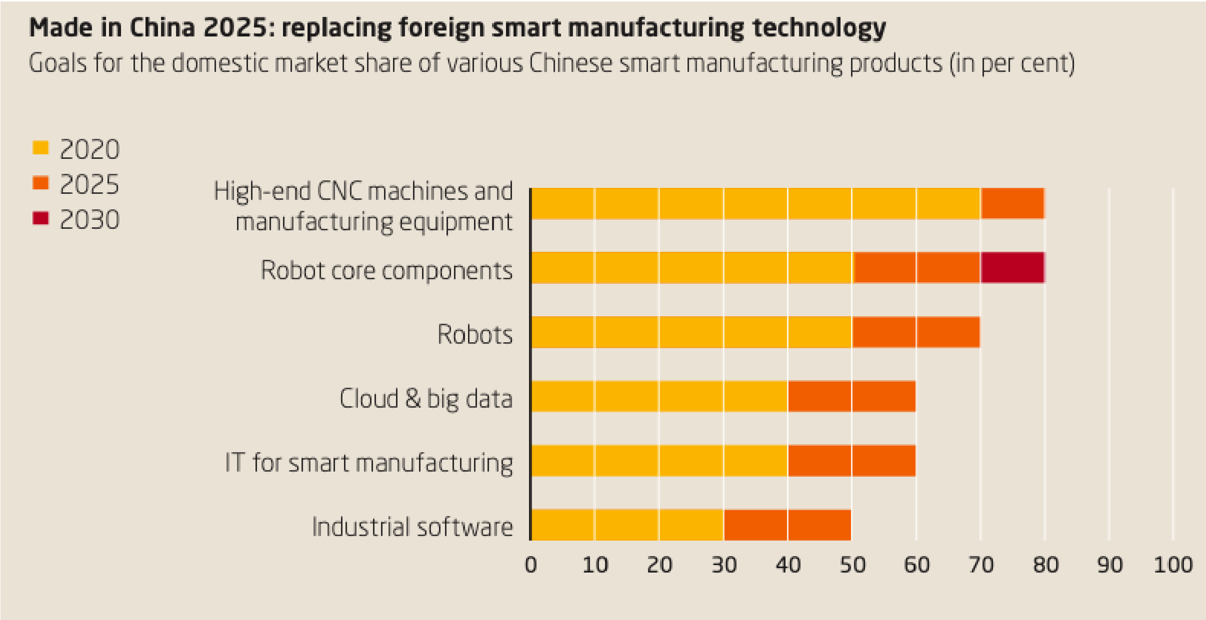

Figure 6: The targeted plan of "Made in China 2025": The percentage of the domestic market share of various Chinese smart manufacturing products forecasted for 2020, 2025 and 2030 (Conrad & al., 2016).

In this prospect, a National Integrated Circuit Investment Fund (National IC Fund) was established and endowed with US$150 billion from the central and provincial governments (Verwey, 2019).

Through those plans, the Chinese government focused mostly on the construction of large fabs and the performance of a few firms such as SMIC, HiSilicon and Tsinghua Unigroup. In 2018, the Chinese government spent more than half of the worldwide semiconductor construction spending (Sauvage, 2019).

Although the Chinese government elaborated the "Made in China 2025" plan, Chinese companies remain very dependent on foreign semiconductor top leading companies and technologies. In 2020, Chinese firms could only produce 30% of its domestic demand for chips. (Craig, 2020). In fact, more than 70% of chips made in China are actually made from foreign companies on Chinese land (van Hezewijk, 2019).

Among the Chinese top semiconductor companies, the largest chip maker is SMIC with an annual revenue of US$3.12 bn (¥20.17 bn) in 2019 (Statista, 2020c).

2.5. Current key players of the industry

Nowadays, as previously mentioned, the semiconductor market is dominated by a limited number of firms (Table 1 and 2).

Table 1: The top 10 largest semiconductor companies in the world by revenue for the year 2019 (Bizvibe, 2020).

Rank	**Company**	**Revenue (USD billions)**	**Headquarters**	**Operating Model**
1	Intel	71.9	USA	IDM
2	Semiconductor division of Samsung[3]	52.19 (Statista, 2020d)	South Korea	IDM
3	SK Hynix	35.27	South Korea	IDM
4	TSMC	35	Taiwan	Foundry
5	Micron Technology	30.9	USA	IDM
6	Qualcomm	24.3	USA	Fabless
7	Broadcom	20.85	USA	Fabless
8	Texas Instruments	14.38	USA	IDM
9	Toshiba	12.3	Japan	IDM
10	Nvidia	11.72	USA	Fabless

[3] Samsung Electronics is a leading South Korean company in semiconductors, telecommunications and digital media technologies. In order to have an accurate comparison of the position of Samsung in the semiconductor industry, only the sales revenue of the semiconductor division of Samsung is mentioned. (Otherwise the total revenue of Samsung Electronics is about US$208.5bn)

Table 2: The top 10 largest semiconductor companies in the world by market value for the year 2019 (Value today, 2020).

Rank	**Company**	**Market Value (USD billions)**	**Headquarters**
1	Samsung	320.01[4]	South Korea
2	TSMC	293.32	Taiwan
3	Intel	263.81	USA
4	Nvidia	145.97	USA
5	ASML	127.54	Netherlands
6	Broadcom	127.20	USA
7	Texas Instruments	126.27	USA
8	Qualcomm	102.71	USA
9	SoftBank	93.51	Japan
10	Micron Technology	61.70	USA

Even though the US semiconductor industry is the global leader in the market, US companies are not leaders in every subsection of the industry. For example, the memory market is led by Korean firms and the discrete semiconductor devices market is governed by European firms such as Infineon and STMicroelectronics (42%) (Figure 7).

[4] This number represents the market value of Samsung Electronics in 2019. As Samsung Electronics is a conglomerate of different companies in different sectors (one of them being the semiconductor sector), the market value of the semiconductor sector of Samsung Electronics is obviously lower. This justifies its position in the table. (See note 3)

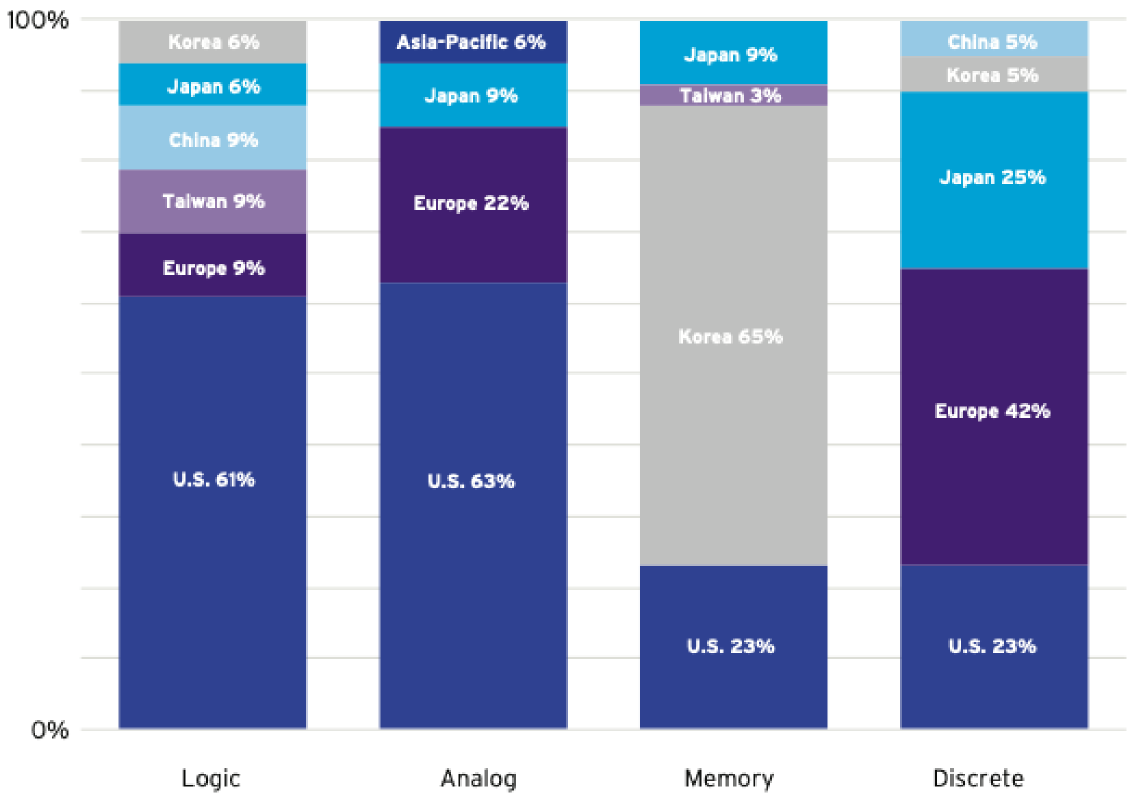

Figure 7: Semiconductor market share by subproducts and countries in percentage (SIA, 2020c).

Due to the rising cost of manufacturing and innovation, and the increasing level of competition in the industry, the US's advance position has decreased in the last few years. In 2010, the US semiconductor industry was two years ahead of its closest competitors, which were South Korea and Taiwan. In 2019, the three countries reached the same level (SIA, 2020c).

This could partially be explained by the fact that the US manufacturing output has remained stable throughout the years while the overall production of new competitors on the market grew at a higher pace. This decreased the US share of the global manufacturing capacity (SIA, 2020c).

2.6. Acquisitions of technology and knowledge protection

Mergers and Acquisitions are still the most used tools for companies that are willing to grow and catch up with leaders in the semiconductor industry (McGrath, 2018).

Japanese and South Korean semiconductor companies are seeking acquisitions in the US and Europe, and also cooperating with China in order to foster their industries. China is also trying to increase outbound investments in high-tech companies in the US and seize global M&As.

From 2014 to 2018, China's semiconductor industry increased its M&A's volume from 48% of the global M&A's volume to 72% with a CAGR of 18% (Chen & al., 2019).

To illustrate this, the table below (Table 3) shows the most important M&As that happened in 2018. As we can see, China and other Asian countries are the most important bidders and their motivations are mostly to extend their market share and their industry supply chain or to strengthen their market position (Chen & al., 2019).

Table 3: Most important global Mergers and Acquisitions in the semiconductor industry in 2018 (Chen & al., 2019).

Date	Bidder	Districted bidder	Target	District of target	Value ($B)	Motivations
2018.07.11	Broadcom Inc.	US	CA Technologies	US	17.987	Expand industry supply chain
2018.03.01	Microchip Technology Incorporated	US	Microsemi corporation	US	9.836	Expand industry supply chain
2018.09.11	Renesas Electronic	Japan	Integrated Device Technology	US	7.004	Search for cutting-edge application
2018.07.25	Tsinghua Unigroup	Mainland China	Linxens Group	France	2.632	Acquire advanced technology
2018.08.15	Will Semiconductor	Mainland China	Beijing OminiVision Technologies	Mainland China	2.178	Strengthen market position and expand market share
2018.05.25	Beijing Electronics	Mainland China	Beijing Yandong Micro-electronics	Mainland China	0.626	Strengthen market position and expand market share
2018.09.14	UKC Holdings	Japan	Vitec Holdings	Japan	0.529	Strengthen market position and expand market share
2018.06.29	United Microelectronics	Taiwan	Mie Fujitsu Semiconductor	Japan	0.519	Strengthen market position and expand market share
2018.11.10	Ingenic Semiconductor	Mainland China	Beijing Xicheng	Mainland China	0.38	Expand industry supply chain
2018.01.31	GigaDevice Semiconductor	Mainland China	Semiconductor	Mainland China	0.268	Strengthen market position and expand market share

** The 6th column named "Value" is express in US$ bn.*

In 2016, M&As accounted for US$120 bn but it has remained stable since then due to tightened regulatory standards issued by European institutions and the US government (Chen & al., 2019).

Indeed, the US government has for several years investigated on the potential theft of US intellectual property and the practice of forcing technology transfers to foreign companies, especially Chinese companies. On the basis of national security threats, the US government has added sanctions to importations and exportations of products from and to China. Those sanctions aim at protecting the know-how acquired throughout the years by US researchers, companies and laboratories. The strategy behind those restrictions is the willingness of the US government to decrease their dependency towards China and to slowly decouple from the Chinese market. The US government wants the production processes that are located in foreign countries, mostly in China, return back home (Nouveau, 2020).

Representing a big threat for the US high-tech industry, the US government has mostly targeted Chinese high-tech companies such as the big telecom group Huawei, known as the Chinese leading firm of the industry. The US government is currently banning all suppliers to ship to this company. It believes that through Chinese companies, the Communist Party is spying on other companies in order to steal commercial secrets and technologies. In this prospect, the US government introduced a U.S. export blacklist, better known as the Entity List that represents a "list of companies, research institutions, governments, individuals or other types of legal persons that are subject to specific license requirements for the export, reexport and transfer of specified items" (Bureau of Industry and Security, U.S. Department of Commerce, 2020). Companies included in this list must apply for a special license given by the US government in order to ship some US products from and to China (Fildes, Hille & Liu, 2020).

As a consequence of the pressure from the Trump administration, US-owned companies located in China such as Apple, Qualcomm and Nvidia have had to remove their factories from China. Relying heavily on the Chinese market and their growing demands for semiconductor products, those companies will have to find solutions in order to keep providing this market while being align with the new US standards (Ioannou, 2020). However, as it is a topical subject inclined to rapid changes, it is still too soon to make an analysis on the impact from the US government's imposed restrictions as well as the strategy posed by US targeted firms.

The Chinese government has released the 14th Five Year Plan this October to respond to the possibly damaging outcomes of the US government's restrictions. The new plan mainly focuses on the pursuit of self-reliance of key Chinese technologies and the growth of scientific

and technological innovation in order for China to be the world's most advanced country by 2035. The plan advances a "dual-circulation" strategy based on the promotion of domestic market circulation and the need to balance Chinese innovative capacity with the domestic demand in the high-tech sector (Ho, 2020). Premier Li Keqiang explained that the national growth target will be at least 6.53% during the next five years in order for the government to meet their goals (South China Morning Post, 2020).
Moreover, as part of the 14th FYP, the Chinese government has passed a law to increase control on exports. It mostly targets countries or regions that abuse export control measures and represent a threat to China's national security and interests (Bicheno, 2020).

Also, the Chinese government introduced a Chinese version of the US entity list called the "Unreliable Entity List". This list represents any foreign companies that have unfair practices against Chinese companies, according to the Chinese government's judgement (Li & Ting-Tan, 2020).

Obviously, the restrictions imposed by the US and Chinese governments impact companies located in both countries. However, the burden will also fall on European and other Asian companies such as TSMC, SK Hynix and NXP because of the partnership they have with both Chinese and US companies (Fildes & al., 2020).
The global supply chain will endorse many disruptions as companies located everywhere in the world will have to put in place a new ecosystem with new suppliers. With this in mind, Chinese companies are already making some changes in their supply chain such as Huawei and Xiaomi that have begun to develop vertically integrated models to make their own chips (Lucas, 2018).

PART 2: Analysis of key success and failure factors of the semiconductor industry

In this part, I will develop and analyze key characteristics of the US, European and Chinese semiconductor industries. Afterwards, I will provide a comparative analysis of the three regions regarding the factors I chose. I will then be able to discuss the effectiveness and the importance of those factors on the development of a country's semiconductor industry.

1. The supremacy of the United States in the semiconductor industry

Nowadays, US firms still dominate the world digital market due to the digital strategy they've developed throughout the years. The US semiconductor industry has about 47% of global market share (Statista, 2020f) which represents an annual revenue of US$193,68bn in 2019 (SIA,2020a). The leading position of the US industry is due to several factors.

1.1. The demand from US military and space industries

During the World War II, the US government had to develop a strategy to combat their enemy, the German. In order to meet wartime needs such as weapons and aeronautics tools, laboratories, companies and the US government have pooled their strengths and collaborated to develop technological innovations (Best, 2018).

To this end, massive R&D investments were made from the US government. Indeed, national laboratories were built in order for engineers and scientists to accumulate R&D resources and technological capabilities. The establishment of national scientific and technological infrastructures benefited the economic development of technological hardware and high-tech products (Best, 2018).

The increasing demand for massive investments from the US government to sustain US defense and space industries continued throughout the cold war. The US semiconductor sector could emerge and self-develop at a higher speed than any other country in the world (Chandler, 2005). After a while, with an increasing demand of integrated circuits coming from NASA, companies such as Texas Instrument, Motorola and Fairchild Semiconductor entered the market (Sauvage, 2019). As an example, Fairchild produced its first IC for the US space industry because they were facing problems with the Apollo program. Texas Instrument also

used military funding in order to develop its manufacturing techniques, improve the products and then market it (Dennis, 2017).
During the years between 1950 and 1964, US$50M was injected in the US semiconductor industry by the military department of the US government (Creager, n.d.).

1.2. Access to economies of scale

US firms were early innovators in the semiconductor industry. As first movers, they were the ones to invent and use this technology. They continuously improved their technics in order to stay leaders of the industry. US companies increased their market share rapidly in their home country and expanded internationally which gave them the advantage to quickly access economies of scale. As they incurred lower cost of production, their products were more affordable than any other competitor. With the increasing number of users comes a greater market power along with a stronger network effect[5] (Nouveau, 2020).
In the same framework, Alexis Wichowski, a professor at Columbia University, called the US tech giants "net states" which describes their ability to be digital non-state actors unrestrained by borders which, in some cases, have more influence than major governments (Chazan & McGee, 2020). This allowed them to have access to natural monopoly rents and to enjoy a pole position in the digital industry.

The global leading position of the US semiconductor industry allows companies to benefit from an innovation cycle. Being leaders in the market, their revenue increase. They are able to invest more in R&D and to improve their products. As consequence, they continuously increase their sales of leading-edge technology products. As long as US semiconductor companies keep their leading position, they will benefit from this innovation cycle (Nouveau, 2020).

[5] The network effect occurs when an increased number of users improves the value of a good or service (Banton, 2020). In this case, as users of semiconductor products increased, US companies earned more and had thus the ability to invest more in R&D and improve their own products.

1.3. R&D expenditures

The R&D expenditure of the US semiconductor industry has always grown during the years at a CAGR of approximately 6.6% from 1999 to 2019 to reach US$40bn in 2019 (Figure 8) (SIA, 2020a). This reflects the growing importance of R&D investments in the global semiconductor industry in order for companies to continuously innovate.

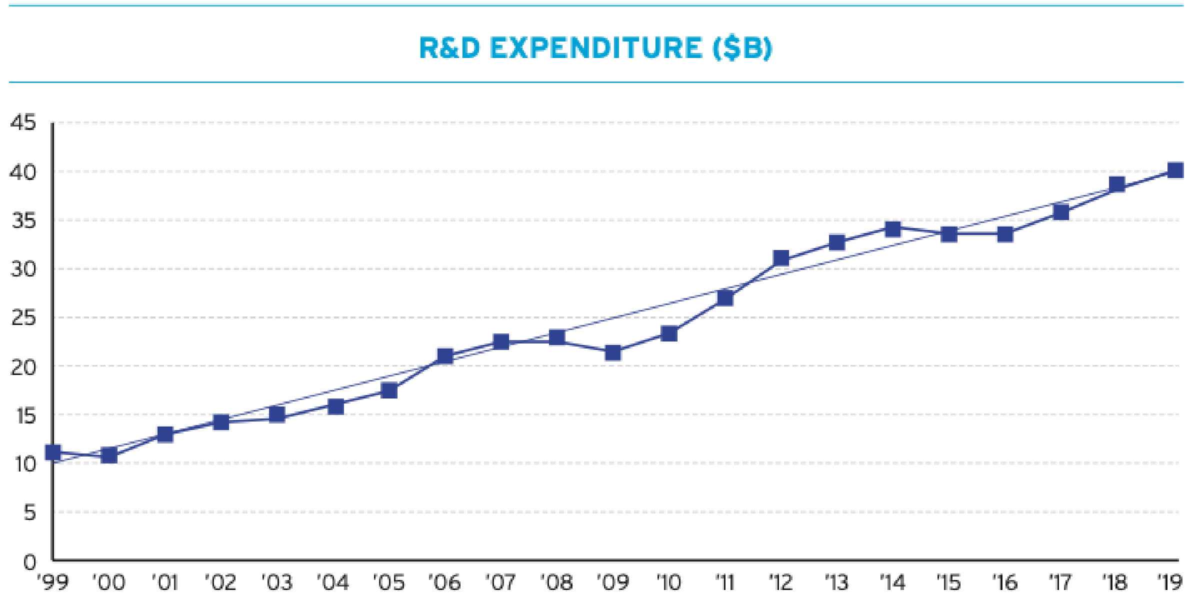

Figure 8: R&D expenditures of the US semiconductor industry in US$ bn from 1999 until 2019 (SIA, 2020a).

While foreign R&D investments are also growing in order to compete with top semiconductor leaders, US firms are trying to keep investments level high and maintain their technological advancements. In 2019, the US R&D expenditures in the semiconductor industry reached about 16.4% of total US semiconductor products sales, which was the highest rate amongst top leading countries in the sector (Figure 9).

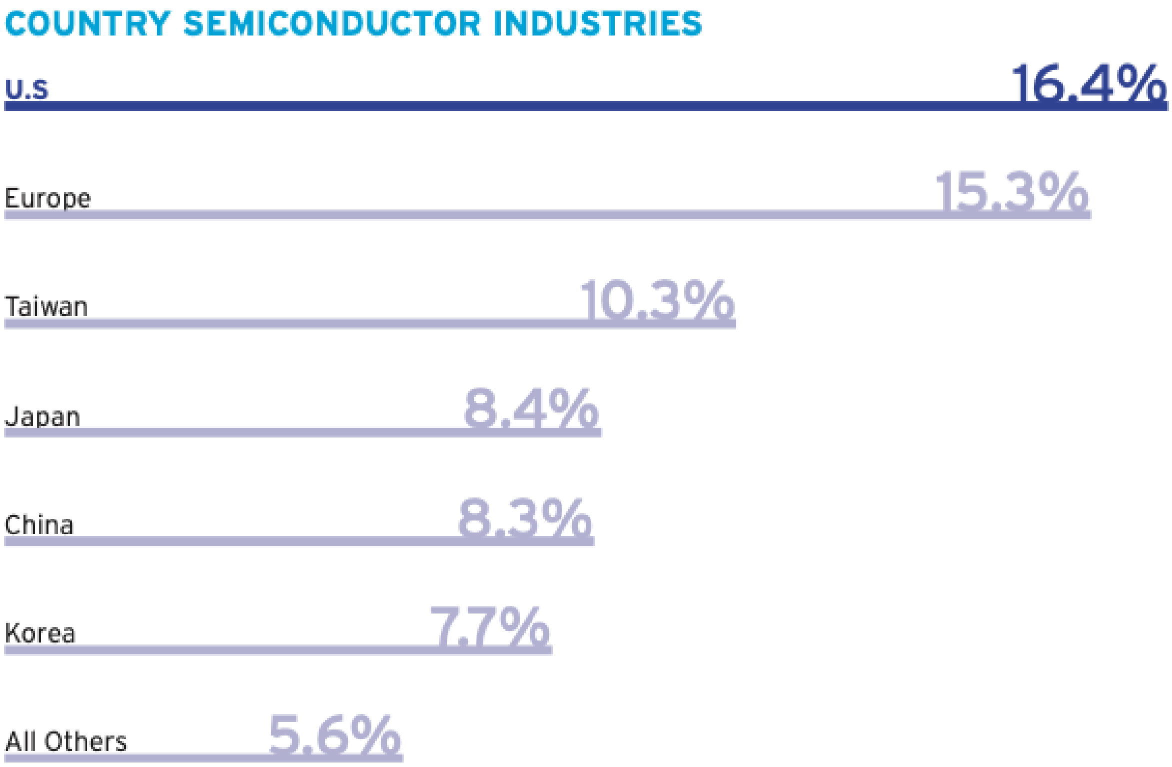

Figure 9: R&D expenditures as a percentage of total sales in the semiconductor industry per country/region in 2019 (SIA, 2020a).

1.4. Workforce

As previously mentioned, the US government tried to develop state-of-the-art production capability and technological diffusion processes during World War time in order to combat the enemy. This was only feasible through the help of the best scientists and engineers with a high level of skills at the operational as well as at the advanced engineering levels. Therefore, the US government has developed a university-industry-government collaboration and has invested in building high-level national universities in order to develop a competent workforce (Best, 2018).

Those universities have maintained their reputation throughout the years which allowed the US government and big companies to attract talented people from all over the world.

Through these collaborations, high-tech companies in the semiconductor industry have access to a highly educated workforce. This increases the competitiveness and the growth rate of US companies in order to remain as leaders in the sector (SIA, 2020a).

1.5. The role of the federal government

The US government has taken decisions, over the past few years, to prioritize the development of industry research, workforce, trade and intellectual property in the semiconductor industry.

In this framework, it has provided several grants and incentives to research agencies, laboratories and companies. Approximately US$1.5 bn to US$5 bn are invested annually by the federal government in the research of semiconductors across different national scientific agencies (SIA, 2020c). For instance, The Department of Energy (DOE), the Defense Advanced Research Projects Agency (DARPA), and the National Institute of Standard and Technology (NIST) each received US$2 bn in 2019 in order to stimulate their research in the semiconductor industry (Lewis, 2020).

Also, in the framework of the CHIPS for America Act, the US government established a new manufacturing grant program in order to construct new onshore advanced semiconductor manufacturing facilities in the US. The government also provides tax incentives for semiconductor manufacturing facilities.

In terms of trade, the USMCA (United State-Mexico-Canada Agreement), was approved on the 1st July 2020. This agreement is an update of the already existing NAFTA. One of its goals is to foster the semiconductor industry in the three countries by protecting companies from IP and technology thefts and assuring the free and open flow of data inside North America (EPS, 2020). Currently, the US government is also enforcing laws to prevent semiconductor intellectual property theft, as mentioned earlier (SIA, 2020b).

Moreover, US semiconductor firms have benefited from aids in R&D coming from foreign agencies and governments. For example, the US firm Intel has received US$10 million in 2017 from the Irish Industrial Development Authority and has also garnered R&D support from Israeli authorities in order to expand foundries in the country.

Unfortunately, this kind of information is mostly confidential. This is why it is complicated to determine the right amount of aids firms receive in order to develop themselves (Sauvage, 2019).

2. The semiconductor industry in Europe

The semiconductor industry in Europe accounted for 10% of worldwide market share in 2019 (Statista, 2020f) and the total sales amounted to approximately US$41.2 bn (SIA, 2020a) which is a 12.1% increase of 2018. However, this percentage is below the 13.7% world average growth of the semiconductor industry (ESIA, 2019).

European semiconductor companies are struggling to compete with international leading companies. Indeed, only one company, ASML (from the Netherlands) is still in the top 10 of the worldwide semiconductor companies in terms of market value (Value Today, 2020). However, European companies seem to be leaders in niche markets. This is due to several decisions made by companies, national governments and European institutions.

2.1. Investments from semiconductor companies

European countries are spending on average 15.3% of their total semiconductor sales in R&D investments which is a little bit less than the 16.4% from the US but more than Asian countries (SIA, 2020a). Also, as we can see on the figure below (Figure 10), European companies, altogether, are spending globally more than 2% of the total GDP in R&D investment which is less than the US spending of approximately 2.7% of its GDP. However, the percentages have increased throughout the years at approximately the same pace. Looking more into China, we can see on the graph that the percentage of R&D investment to its GDP grew at a faster pace and exceeded the European Union (Nouveau 2020).

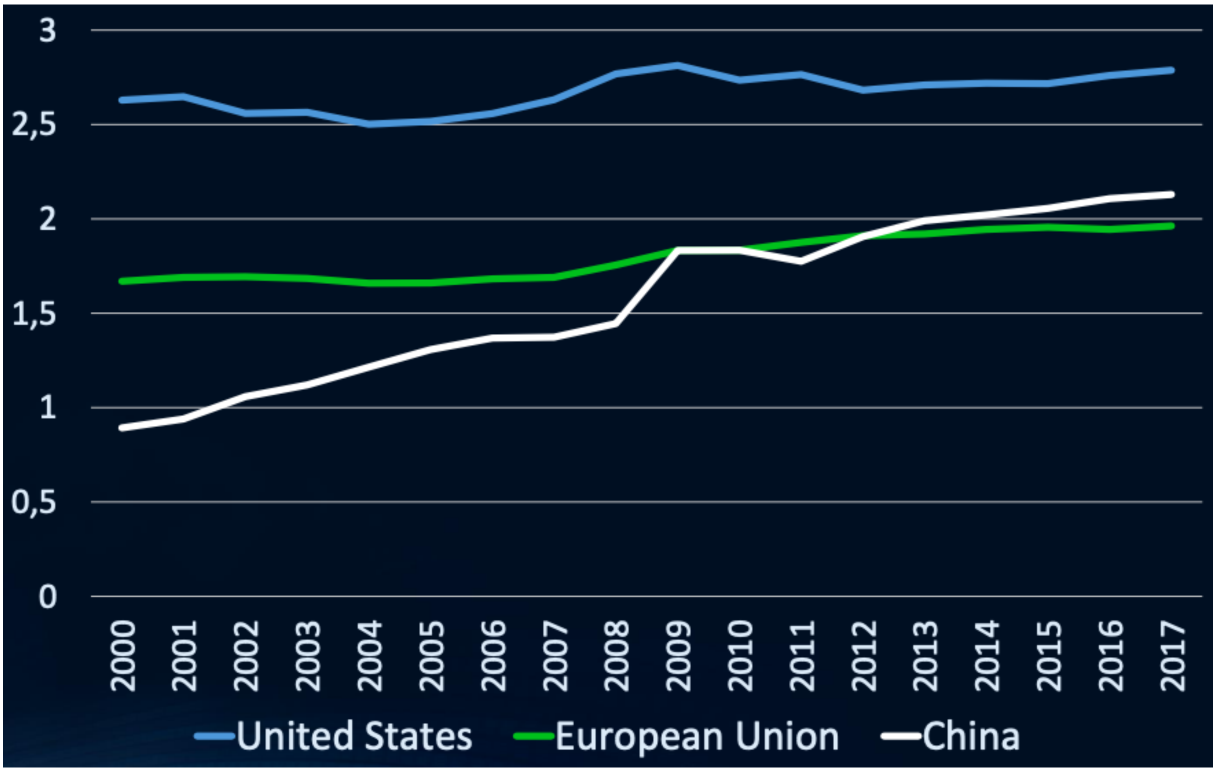

Figure 10: R&D expenditures as a percentage of GDP of the US, EU and China from 2000 until 2017 (Nouveau, 2020).

According to a report made from the ESIA (2020a), in 2009 the European semiconductor industry ranked at the top for R&D investment intensity with a record of 21.8% of annual R&D expenditure over annual sales, followed by the US with 19.1%. At that time, the worldwide R&D intensity in the semiconductor industry was about 16.8%. (Appendix 1) Those European R&D investments in the semiconductor industry were mostly used for the automotive industry, medical devices, and smart cards (ESIA, 2020a).

However, since then there has been a rising global technological growth rate and stronger geopolitical tensions. This led US and Chinese companies to sharply increase their R&D investments in Information and Communication Technology (ICT) by 10.3% and 26.7% respectively while European companies have only increased their R&D investment by 4.7%. This has changed the position of the European semiconductor industry in the top intensive R&D investments (Amoroso & al., 2019).

In general, Germany, the UK and France are the three countries in Europe that spend the most in R&D and account for 68.4% of the total EU R&D in 2019. Most of the R&D spending in

Europe are for the automotive industry which was also the case in 2011. In comparison, the high-tech sector has the most R&D growth rate in China and in the US (Amoroso & al., 2019).

It is known that semiconductors require a lot of R&D investments but also faces great expenses for the manufacturing equipment in order to build fabs and implement manufacturing processes. The cost to build a new fab is about US$18 bn to US$27 bn. (SIA, 2020c) EU companies, together, invested US$3,26 bn for manufacturing equipment and facilities in 2019. This number ranked the European Union at the lowest place compared with other countries in the sector. The country that spend the most in manufacturing expenditures is Taiwan with US$15.8 bn followed by China with US$12.91bn (Statista, 2020b).

2.2. Aids and incentives from European Institutions and national governments

Since several years, European institutions have tried to promote the European semiconductor industry through the establishment of standards and programs for European companies.

In 2013, the European Commission put in place an EU-wide strategy for micro- and nano-electronic components and systems with the objective to reverse the declining European share of the world market. In order to sustain this plan, governments and companies should invest at least US$121.45 bn (€100bn) by 2025 (Ezell, 2020). To this end, the Electronics Leaders Group (ELG) was built and given the task to set up a roadmap to implement the strategy. Since then, the Research & Technology Organizations[6] (RTOs) have established a deep cooperation strategy with the European Commission, the Member States, regions, and European companies throughout the value chain. Two plans were launched in 2014 at a European level in order to sustain this strategy: The ECSEL Joint Undertaking and the IPCEI Instrument (Important Project of Common European Interest). The first one aims at providing a model for public-private collaboration in the digital arena. This collaboration could improve the semiconductor value chain by shortening the vertical chain and extending the horizontal chain. The second plan provides a framework for investing in the European semiconductor industry which will enable European companies to compete with foreign leaders.

[6] Research & Technology Organizations are a group of non-profit organizations that cooperate with companies and public actors in order to improve technologies in a wide range of scientific fields. (EARTO, 2020)

The goal was to encourage private and public investments in R&D&I within the semiconductor supply chain (European Commission, 2018). Since the launch of the program in 2014 until 2020, US$3.1 bn have been invested in ECSEL projects (Ezell, 2020). However, data about how much was already spent for this EU-wide strategy has not been released.

In 2015, the European Commission launched the "Smart Anything Everywhere" (SAE) initiative which provides SMEs an easier access to RTOs and supports them to use digital technologies in order to innovate their products. As there are many SMEs in the European market, the SAE was created to improve their ability to afford the high cost that the global semiconductor industry requires.

EUREKA clusters, funded by Member States, are also playing an important role to promote R&D investments of semiconductor companies. Indeed, their aim is to facilitate the funding of R&D in new technologies (Eureka Network, 2020). In 2018, US$3.2 bn (€2.6 bn) have been invested in 51 projects and involved more than 1,600 research, development and end-user organizations (European Commission, 2018).

Nowadays, the European Commission is working on the next framework called Horizon Europe which will be the successor of the Horizon 2020 framework. The agreement has still to be formally approved by the European parliament and the Council of the EU.

This framework will sustain EU research and innovation programs with a budget of US$115.67 bn (95.5bn€) from 2021 until 2027 representing on average US$19.27 bn per year. This is a 30% increase from the current program. According to Mariya Gabriel, the European commissioner for Innovation, Research, Culture, Education, and Youth, the Horizon Europe program will strengthen the scientific and technological base to drive digital transformation.

However, the budget that will be dedicated to the development of the high-tech sector and more specifically to the semiconductor industry hasn't been released yet. Moreover, given the current challenges, the European Commission will prioritize the health sector and the environmental issues more than the ICT sector (European Commission, 2020a).

The European Commission has also announced a new "Sustainable and Smart Mobility Strategy" as part of the 2020 European Green Deal. This strategy aims at creating energy efficient means of transportation. The technologies to develop such strategies require a lot of semiconductor components. On the condition that European automotive manufacturing companies will seek European semiconductor products, this will foster even more the current global position of European suppliers of advanced automotive semiconductor products (ESIA, 2020c).

2.3. The fragmentation level in the European market

One problem Europe is facing, as opposed to other countries in the industry, is the high level of fragmentation in the European market. Indeed, the European Union is constituted by 28 Member States that all have their national government, standards, and regulations. Every country inside the EU is acting following its own interest. By consequence, the level of cooperation and coordination among EU countries is weak. Compared with the US or China, the European Union is highly fragmented. As an example, the European decision-making process is slower than in China or in the US as it requires a second level of approval above the national level (European Commission, 2018).

Although the European Union is seen as a Single European Market[7] (SEM) for European companies, they do not benefit from a large unified home market as the US or Chinese companies do in their home country (Kearney, 2020). This is due to diversities and divergences among regulations and standards of the different countries. Semiconductor companies willing to do business in several European countries have to comply with each jurisdiction.

Also, to this day, there are no single semiconductor markets among Member States that can bear the cost of R&D&I and keep up with the speed of technological advancements. To illustrate, based on the revenue of three large European semiconductor companies that are headquartered in three different countries such as ASML in the Netherlands, Infineon in Germany and STMicroelectronics in Switzerland, we can observe that without cooperation between countries and a pooling of investments from companies, the level of R&D investments for each companies is low. Moreover, there are chances that investments will be

[7] The Single European market (SEM) is based in the four freedoms of movement: freedom of movement of people, goods, services and capital. It aims at stimulating competition and trade, improving efficiency of companies, raising quality and helping to decrease prices. (European Commission, 2020e)

used to develop the same technology or innovation which will turn companies into competitors for that technology. However, if those companies are pooling their investments together, they are able to invest US$5.04 bn into one common project which will make the investment more efficient.

Table 4: Revenue of ASML, Infineon and STMicroelectronics in 2019 and their R&D investment in semiconductor.[8]

	Revenue of semiconductor products in 2019	**R&D investments (=15.3% of revenue)**
ASML (The Netherlands)	US$13.54 bn (€11 bn) (ASML, 2020)	US$2.07 bn
Infineon (Germany)	US$9.881 bn (€8.029 bn) (Infineon, 2020)	US$1.51 bn
STMicroelectronics (Switzerland)	US$9.56bn (GlobeNewswire, 2020)	US$1.46 bn
Total		US$5.04 bn

2.4. Niche markets in Europe

European countries have mostly invested in traditional sectors such as the automotive, mobility, security and healthcare industry (Nouveau, 2020). Those segments have a high demand for semiconductor products which allowed European companies that specialize in those segments to grow and increase their global position. Bosch (Germany), NXP (The Netherlands) and Infineon (Germany) are the most important suppliers in the market. There are also market leaders for security chips for passports, IDs, and smartphones (NXP, Infineon and ST Microelectronics). In terms of investment, EU companies in the semiconductor industry target US$25,13 bn (€21 billion) for manufacturing and US$34,7bn (€29bn) in R&D&I from 2018 to 2025 (Coulon & al., 2020).

[8] The third column of table 4 (R&D investments) is calculated on the basis of the revenue of each company (the second column of table 4) multiplied by 15.3% which is the R&D expenditures of European semiconductor companies as a percentage of their total revenue (SIA, 2020a).

By contrast, some European semiconductor companies have lost their position on other markets where semiconductor products are used, giving the lead to US or Asian companies. For example, if we look at the manufacturing of chips, Taiwan, which is a smaller country compared to the Europe Union, produces 20% of all semiconductors, South Korea about 15%, and Singapore for 7%. Furthermore, the most advanced plants for manufacturing semiconductors are now located in Taiwan and South Korea (Ott, 2018). To illustrate this, we can see on figure 11 that the Asian pacific region produces around 60% of the overall semiconductor products while European companies only produce 10% and kept decreasing over the years (Coulon & al., 2020).

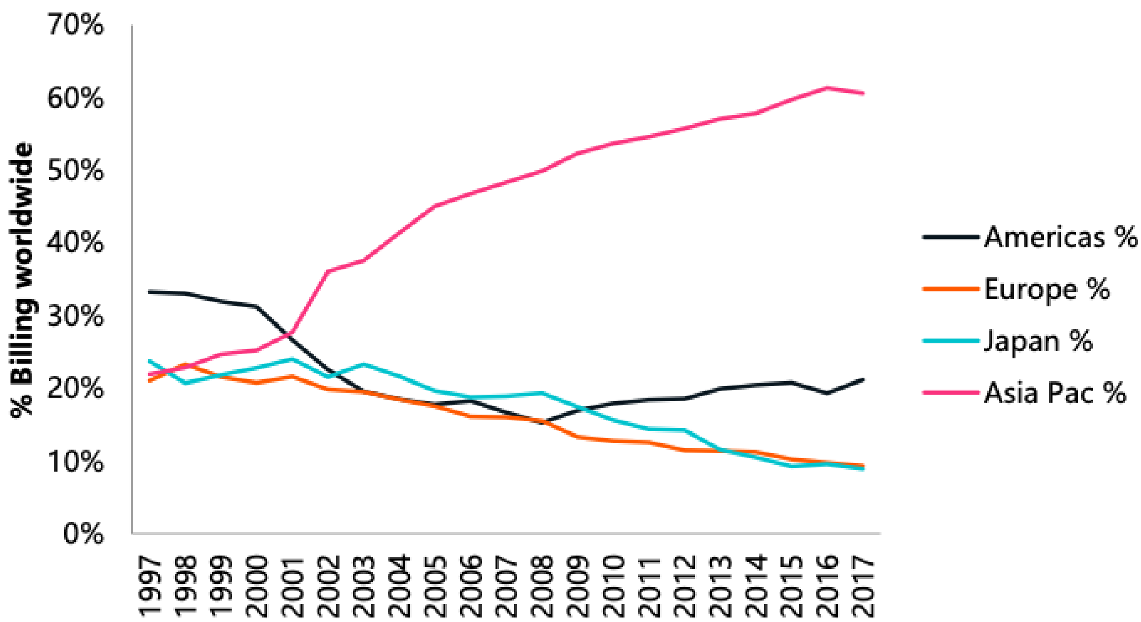

Figure 11: The semiconductor outputs per countries as a percentage of the global semiconductor outputs from 1997 until 2017 (Coulon & al., 2020).

3. The semiconductor industry in China

The Chinese semiconductor industry is the world's fastest growing industry. According to the Nasdaq-style Shanghai STAR Market, China's leading semiconductor firms have increased their sales by 16% from 2019 (Shenshen, 2020), despite the coronavirus pandemic while the global semiconductor sales increased by only 5.8% (SIA, 2020b).

Among Chinese top semiconductor companies, the largest chip maker is SMIC with a revenue of US$3.12 bn in 2019 (Statista, 2020b). By comparison, the worldwide leading firm in the industry, Intel reached US$71.97 bn in revenue in 2019 (Statista, 2020a).

3.1. Governmental aids and policies

As previously explained, the Chinese government has planned to decrease its dependency towards foreign semiconductor products. To this end, Chinese semiconductor companies should first expand acquisitions and invest in foreign leading firms to increase technology transfers and reduce the technological gap.

In this regard, since 2001, the Chinese government has revealed several Five Year Plans targeting the high-tech sector and more specifically the semiconductor industry.

As Part of the 10th, 11th, and 12th FYP, the Chinese government decided to invest US$260 bn for the establishment of "the Medium and Long-Term Plan for Science and Technology" (Sauvage, 2019).

In 2015, in the 13th FYP framework, the Chinese government released following strategic plans that cover the goals and guidelines of the Chinese semiconductor industry: "The Guidelines to Promote a National Integrated Circuit Industry", "Made in China 2025", and "The Made in China 2025 Technical Area Roadmap". Those plans allowed the establishment of national funds such as the National Integrated Circuit Investment Fund (National IC Fund) by which US$150 bn was invested in the Chinese IC sector from central and provincial governments. The Fund aims at fostering inbound and outbound FDI (VerWey, 2019). In 2017, the SIA estimated that US$80 bn out of the US$150bn was already raised.

in October 2020, the Chinese State of Council released the 14th FYP clearly targeting the self-reliance of the Chinese semiconductor industry. This has clearly been the results of the increasing tensions between the US and China in the high-tech sector. The Chinese government has noticed the importance of being technologically less dependent on other countries (Ho, 2020).

Since 2011, the Chinese government has provided several aids such as regional, provincial and national funds, investment vehicles, equity investment, favorable loans, tax breaks, and policies aiming at reducing capital expenditures of Chinese companies in the sector. The goal is to prompt Chinese enterprises to increase their R&D investments in the semiconductor industry by decreasing their manufacturing cost of building new fabs (Deloitte, 2020). The Chinese government has planned to invest US$100bn in subsidies to support its national semiconductor industry (SIA, 2020b).

However, it is difficult to provide a deep analysis of all funds and investments made by the Chinese State Council for the Chinese semiconductor industry as it counts around 1,600 government-guided investment funds involved for the “Made in China 2025” strategy plan. The National IC Fund is one of them. Those funds represent a capital of US$584.8 bn and new funds are created every month in order to finance governmental strategies (Huang, 2019).

3.2. Investment strategies from semiconductor companies

With the help of grants and subsidies received by the Chinese government, Chinese companies in the semiconductor industry are able to increase the number of M&As and joint ventures with foreign firms. As previously seen (Table 3), in 2018 most of them were made from Chinese enterprises. From 2014 until 2018, the Chinese M&A’s volume increased from 48% of the global M&A’s volume to 72% with a CAGR of 18%. Chinese companies have made the most outbound semiconductor deals during the past five years, amounting to 49 deals, followed by Japan with 13 deals. (Chen & al., 2019) Those investments targeted companies throughout the whole semiconductor supply chain process from upstream equipment manufacturers to companies specialized in ATP (VerWey, 2019).
However, the number of M&As and joint ventures with European and the US companies has stabilized since a few years as both regions are willing to protect their market from technological transfer (Congressional Research Service, 2020).

In terms of investment for manufacturing equipment and building fabs, Chinese companies have been massively investing since a few years. In 2019, Chinese firms have invested US$12.91 bn which made them the second country to spend the most for semiconductor infrastructures, following Taiwan with US$15,.58 bn (Statista, 2020b).

Through the analysis of the Chinese companies' investments, we noticed the importance of the state's role behind those so-called "private investments". Indeed, most companies in China are strongly supported and guided by the Chinese government. The investments made by companies are mostly managed by Chinese funds which are created by the Chinese government for the development of its semiconductor industry. Those funds, such as the National IC Funds, were created at first to subsidize Chinese enterprises. However, they are now increasingly used for overseas investments (Conrad & al., 2016).

3.3. Protection tools from the Chinese government

Align with the willingness to make its semiconductor market grow, the Chinese government wants to protect its market from competitors. It, thus, implemented a high level of control and a wide range of restrictions on foreign semiconductor-related firms. This aims at restricting access to those companies and providing the space that Chinese semiconductor enterprises need to develop.

In most industries using the internet, foreign companies are submitted to data and cyber control from the Chinese government. In 2017, the Chinese government has introduced a new Cybersecurity Law targeting every firm dealing with digital data and importing foreign IT in China (Lewis, 2020). Those companies are obliged to conform with the Cybersecurity Law and the sharing of sensitive information. This information has to be stored beyond Chinese borders and thus increases the risk of information leaks. Concerning the importation of foreign technologies, the "Administrative Rules for the Commercial Use of Encryption" allows foreign companies to only introduce technologies in China that are approved by the Office of State Commercial Cryptography Administration (OSCCA) (Alsabah, 2017).
In addition, in May 2018, the Personal Information Security Specification, an extension of the 2017 Cybersecurity Law, was established to regulate the use and storage of personal data. The updated version forces even more foreign companies located in China to comply with investigative measures and to disclose any information required by the Chinese government (Lewis, 2020).
However, these cyber regulations are vague and lack precision on the investigation process and the companies that are targeted.

Moreover, the Chinese government has introduced the certification of trustworthy products that strongly affects international tech firms. This certification is given by the Social Credit System which rates companies on criteria such as the economic and social trustworthiness. It aims to regulate the access to the Chinese market (Conrad et al., 2016).

Also, to respond to the US Entity List, China's Ministry of Commerce (MOFCOM) introduced the so-called "Unreliable Entity List" in September 2020. This list represents any foreign companies that have unfair practices against Chinese companies, according to the Chinese government's judgement (Li & Ting-Tan, 2020). The MOFCOM announced that the final provision is based on the Foreign Trade Law, the National Security Law, and "other relevant laws" (Zhang, 2020).

As we can see, whenever foreign high-tech companies enter the Chinese market, they have to comply with those Chinese regulations and accept the costs of adaptation. If foreign companies want to provide products to China, they have to undergo their production process following special Chinese standards and pay some royalty fees. The aim of the Chinese government is to increase the cost endorsed by foreign companies (Conrad et al., 2016).

3.4. The importance of the Chinese market

China is the world's largest purchaser and importer of chips due to the increasing presence of semiconductor companies inside Chinese borders. Nowadays, every big company in the sector is present in China ranging from R&D centers to fabrication facilities. In 2019, 90% of global smartphones, 65% of personal computers, and 67% of smart televisions were made in factories located in China. As an example, the U.S. Census Department's related Party Trade database shows that about 60% of all U.S. imports of semiconductors from China actually come from a subsidiary of a U.S. headquarter located in China. (VerWey, 2019).
A reason for this high percentage is due to lower labour cost. According to trading economics, the labour cost index[9] illustrating the hourly labour cost incurred by employers in nominal

[9] The Labour Cost Index is calculated by dividing the labour cost in national currency by the number of hours worked. The total labour costs (TOT) comprise wages and non-wage costs less subsidies. (Trading economics, 2020)

terms, is at 81.4 in China, 107 in the European Union and 116 in the United States (Trading Economics, 2020).

Moreover, China has a large demand for chips that keeps growing. As the figure 12 shows, China is the only market in which the demand for semiconductor grew this much in the past few years. In 2016, the consumption of semiconductor products in China was about 57% of the worldwide semiconductor products representing a total of US$365.60 bn. Hence, it is interesting for foreign companies to be located as close as possible from their main clients (Pwc, 2019).

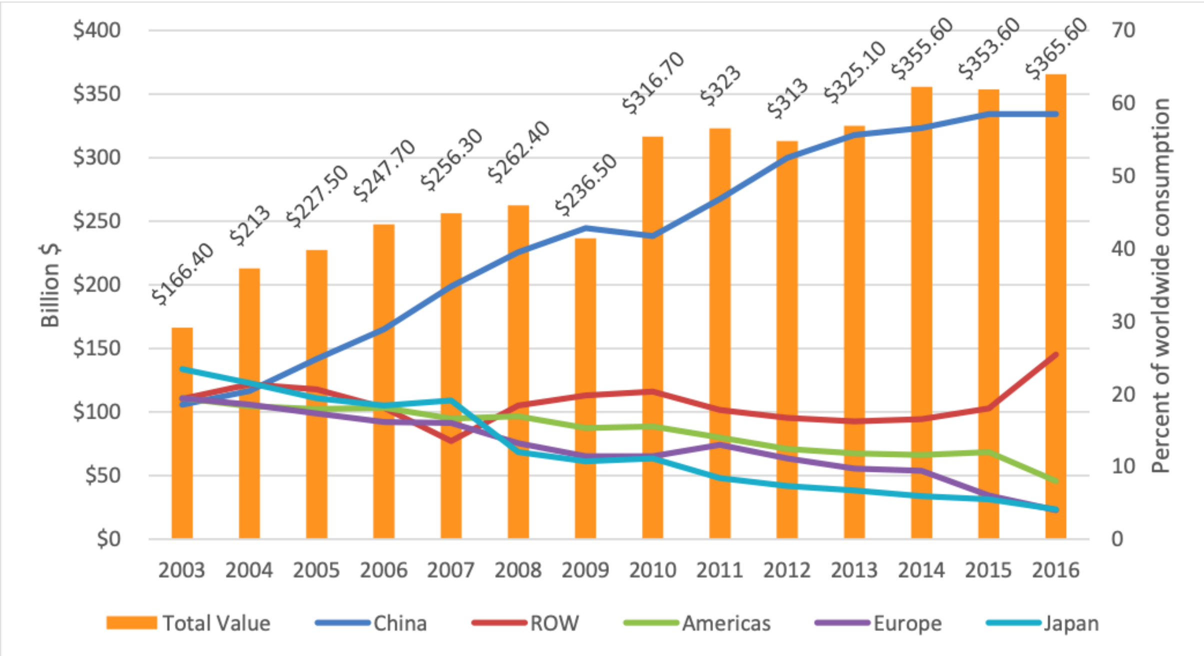

Figure 12: Worldwide semiconductor consumption market by region in US$ bn (left) and percentage of worldwide consumption (right), from 2003 to 2016 (Pwc, 2019).

Note: ROW = Rest of The World

4. Comparative table

		United States	Europe	China
The role of the Defense and Space industry[10]	General comments	Introduces the US semiconductor industry	No single entity defense system	Growing spending of military expenditures
	Military expenditures in 2019	US$732 bn	US$365 bn	US$261 bn
	Military expenditures as a percentage of general government's expenditures in 2019	9,7%	2,7%	5,4%
	Military expenditures as percentage of the national GDP in 2019	3,4%	1,2%	1,9%
Network effects and innovation cycle		Yes, precursors in the semiconductor industry	Yes, prime movers with Japanese and US firms	No, Chinese companies entered the international market in the beginning of the 21st century
Investments by companies in the semiconductor industry[11]	R&D investments in 2019	US$40 bn	US$5.9 bn	US$9.27 bn
	R&D investments in percentage of country's semiconductor sales	16,4%	15,30%	8,30%

[10] Sources for this table line: (SIPRI, 2020)
[11] Sources for this table line: (SIA,2020a), (Statista, 2020c), (European Commission, 2020c)

	R&D investments as a percentage of the national GDP in 2019	2.7%	2%	2.1%
	Growth rate of investments in ICT in 2019	10.3%	4.7%	26.7%
	R&D investments in ICT as percentage of the overall national R&D investments in 2019	52%	20%	47.11%
	Investments in building fabs in 2019 by semiconductor companies	US$7.78 bn for North America	US$3.26 bn	US$12.91 bn
Governmental aids[12] - **Financial incentives** - **Policy and standards** - **Programs**		- Investments and subsidies to US research department: 5bn/year in researches, US$4bn to DOE, DARPA & NIST - CHIPS for America Act - Law enforcement against IP theft: "Entity List" - USMCA	- EU-wide strategy for micro- and nanoelectronics components and systems and implementation of ELG and RTOs : US$121.45 bn - SAE program and Eureka Clusters - Horizon Europe: US$114.67 bn from 2021 until 2027 - Sustainable & Smart Mobility Strategy	- The 10th, 11th, 12th FYP and the establishment of "the medium and long term plan for Science & Technology": US$260 bn - The 13th FYP : Made in China 2025, Guidelines to promote a National IC Industry and technical roadmap : US$150 bn - Since 2011: US$100 bn in subsidies for

[12] Source for this table line: (Lewis, 2020), (Ioannou, 2020), (SIA, 2020c), (Ezell, 2020), (European Commission, 2020c), (European Commission, 2018), (ESIA, 2020a), (ESIA,2020b), (Sauvage, 2019), (Verwey, 2019)

				manufacturing equipment
Cooperation and collaboration		Yes, one single country with one decision-making system	High level of fragmentation among Member States	Yes, one single country with on decision-making system + Government implication in investment strategies
Dependency on foreign country[13]	Imports of Integrated Circuits in 2018	US$26.1 bn	US$58.7 bn	US$133 bn
	Exports of Integrated Circuits in 2018	US$37.1 bn	US$50.9 bn	US$90.9 bn
	Number of granted patents of the first national ICT firm in the IFI ranking in 2020	IBM with 37,304 granted patents	Siemens with 25,320 granted patents	Huawei with 12,315 granted patents
Level of protection of the semiconductor market		- Entity List - Increasing trade tariffs	- EU Cybersecurity Act	- Unreliable Entity List - Data and Cybersecurity Laws - Certification of Trustworthy products
Level of universities, education and workforce[14]	Number of national universities among the top 25 best Engineering and Technology universities in the world in 2020	8	8	2

[13] Source for this table line: (OEC, 2020); (IFI,2020)
[14] Source for this table line: (QS, 2020), (Withers, 2020), (OECD, 2020)

	GCTI ranking	3rd	11 European countries in the top 20	Not present in the ranking
	Number of Graduate students in Engineering and Science in 2018	940,000	298,930	Data not found
Access to the Chinese market		Take over the market share between the Chinese production and demand + Lower labour cost	Infineon & NXP have their biggest revenue share from China + Lower labour cost	Facilitate technology and knowledge transfers

5. Analysis of the comparative table

The table above shows a comparative analysis on key factors for the three semiconductor industries. Below, I will discuss each of these factors regarding the tree regions. I have the intention to figure out which factor is effective and relevant in the development of a country's competitiveness in the semiconductor industry.

5.1. Demand coming from the defense and space industries

As already mentioned, the demand for innovative products from the military sector during the World War II introduced the US semiconductor industry. Afterwards, US companies have developed and innovated more semiconductor products in order to comply with the increasing demand from US defense and space industries.

In terms of global military expenditures, the US government spent more than any other country in the world, amounting at US$732 bn in 2019. The second largest spender in the sector is the European Union with US$365 bn. The Chinese government spent US$261 bn (SIPRI, 2020).

The US government decreased its military expenditures by 17% from the past decades while China has consistently increased its military expenditures by 83%. However, since 2018, US expenditures have grown by 5.3% which represents an increase of US$36.6 bn. This equals the total German military expenditures in 2019 (European Commission, 2020f). European expenditures have remained mostly stable during that period, with a noticeable slight decrease in percentage of GDP and government expenditures. Since 2018, the European Union also increased its military expenditures (SIPRI, 2020).

An important aspect to highlight when analyzing the numbers is the lack of one single defense system in Europe. Indeed, Member States have their own defense system meaning that the total amount of EU military expenditures in the comparative table represents the sum of the Member States' military expenditures. The level of the three different defense expenditures are thus not comparable. If the European Union wants to compete with the US or China, a single European defense system should be implemented with one decision-making process and common investments from all EU Member States.

Although we obtain data for general defense and military expenditures, the amount that is assigned to R&D and the high-tech industry isn't mentioned. Therefore, we cannot conclude that the more a country spends for its military sector, the more its semiconductor industry is growing.

5.2. Network effects and innovation cycle

Companies can benefit from the network effects and innovation cycle only if there is a sufficient number of users and sales volume in the market. As illustrated in the graph in Appendix 2, we can observe that sales of semiconductor products have continuously grown from 1987 until 2000 (Statista, 2020e). As the number of competitors on the market at that time were low, the market share of semiconductor companies, mostly Texas Instrument, Motorola, Fairchild, Siemens and Philips were high. This means that an increase in the number of sales had a direct positive impact on their revenue. Consequently, companies can invest more in R&D to provide better technologies and products. At that time, US and European companies benefited from network effects and the innovation cycle.

To illustrate, although Germany doesn't have any company in the top 10 of the world largest semiconductor companies, the German semiconductor industry reaches the highest amount of sales in the European semiconductor industry with US$15,78 bn (12.88bn€) in 2018. It represents 40,63% of the European market share which makes Germany the first country in the European semiconductor industry in term of revenue (Statista, 2020f).

As previously mentioned, the emerging fabless-foundries model in the late 90s increased the number of competitors on the market. In addition, the offshoring of companies in the beginning of the 21st century to Asia because of lower labour cost destabilized European semiconductor companies. They lost great market shares in the sector. The US companies were able to stay competitive on the market (Value today, 2020) because they kept high level of R&D investments and developed aggressive strategies (SIA, 2020a).

In the start of the semiconductor industry, China wasn't able to develop its semiconductor industry because of a lack of resources and efficient strategies. While Chinese companies were entering the international market, there were already several well-established companies in the global semiconductor industry. Chinese companies couldn't benefit from the innovation cycle and network effects.

However, new emerging technologies are entering the market such as AI and 5G. The number of competitors specializing in these technologies is currently low and the market is not mature yet. This represents a great opportunity for companies willing to improve their position on the semiconductor market.

5.3. Investments in R&D and manufacturing equipment

The semiconductor industry requires large amounts of R&D investments to continuously improve the technology and the end-user products.

US semiconductor companies are spending a total of US$40 bn in R&D in 2019 while European companies spent US$5.9 bn and Chinese companies spent US$9.27 bn. However, R&D investments in the semiconductor industry in terms of percentage of GDP for each country and region are quite similar (respectively, 2.7%; 2% and 2.1%) (Nouveau, 2020). The percentage of R&D investments in proportion of sales is lower for Chinese companies but the growth rate of investments in ICT throughout the year is the highest with 26.7% (Amoroso & al., 2019).

Furthermore, we can observe that Chinese and US companies are mostly investing in ICT with 47.7% and 52% of their total R&D investments respectively. European companies however are only investing 20% of their R&D investments in ICT. European companies active in traditional sectors such as the automotive, healthcare, and smart cards industry, are investing the most in R&D. Also, Germany, France, and the UK have the highest R&D investment rates, reaching 68.4% of the European R&D investments (European Commission, 2019).

Investments in manufacturing equipment is important in the semiconductor industry because of the constant need for state-of-the-art products. As we already mentioned, the cost of building a new fab is about US$18bn to US$27bn. Chinese companies invested US$12.71bn in equipment for the building of fabs in 2019 while European companies only invested US$3.26bn. US and Canada spent together US$7.79bn (Statista,2020b). Chinese companies represent the second biggest spender in fab capex after Taiwan. In general, Asian countries in the semiconductor industry spend the most in equipment and, as a matter of fact, 80% of chip manufacturing currently occurs in Asia.

Also, the advancements in technologies increase the cost of building adequate fabs. As a report from McKinsey (2020) explained, the cost of building a facility with 5nm[15] production lines is three times more expensive than fabs with 10nm production lines. This implies that companies that are willing to produce state-of-the-art technologies should invest a higher amount of fab capex.

A good indicator for the level of R&D investments of a company is the number of granted patents it has. Patents are granted to a company for innovative discoveries and developments. It allows the company to produce unique products, use unique manufacturing processes or even license their use to others for compensations. Patents are mostly protected by Intellectual Property Rights. In January 2020, semiconductor companies such as Samsung Electronics, IBM, Siemens, Intel and Qualcomm were among the biggest patent holders in the world (IFI, 2020).

Indeed, most of the semiconductor companies that hold patents are from the US and Europe. The first Chinese company in the ranking of world's largest active patent holders in 2020 is Huawei in the 29th place. This highlights the innovation gap between Chinese and US firms and to a lesser extent, European companies (IFI, 2020).

As seen in the comparative table, European companies are the lowest semiconductor investors compared to Chinese and US companies. However, as stated by a study from Applied Materials in 2018, many foreign top semiconductor companies are either investing in and establishing partnerships with European research centers and laboratories or setting up new R&D centers in Europe. Indeed, Europe counts several laboratories and research centers such as Leti in France, IMEC in Belgium and the Fraunhofer Institute in Germany. In fact, in the last

[15] The 5nm production lines are made to manufacture 5 nanometer transistors which is an upgrade version of the 7nm transistors and the 10nm transistors (McKinsey, 2020).

five years, Huawei, Sony, Apple and Samsung have mostly invested in R&D centers in Germany, UK and France in order to develop their knowledge in the AR/VR sector and the automotive industry (Hars, 2018).

5.4. Governmental aids

Governmental aid represents financial incentives, implementations of programs and settings new standards and policies to enhance the national market. Evidently, these incentives are fundamental to the development of the semiconductor industry in a country. Governments provide help to national companies in order to decrease their cost and increase their ability to innovate and compete in the international market.

The US government has provided several subsidies to US research departments such as the DOE and DARPA (Lewis, 2020). It also introduces the “Chips for America Act” providing basic standards for US semiconductor companies. The US government also collaborated with Mexico and Canada to create an upgraded version of the NAFTA, called USMCA. This agreement emphasizes the importance of protecting the national intellectual property and technology (SIA, 2020b).

In the context of the trade tensions between the US and China, the US government wants to see a relocation of its high-tech firms back to the US. This will generate higher cost for US companies. First of all, the cost of building new fabs in the US varies between US$18 bn and US$27 bn, depending on the technology used by the company (Statista, 2020b). Second of all, enterprises will have to employ US workers which will increase the cost of labour by 142% compared to China (Trading Economics, 2020). In other words, unless a sufficient amount of incentives is provided by the US government, companies could be discouraged by the high costs they will have to endure from relocating to their home country.

The European Commission has also implemented several programs and standards to foster its semiconductor industry. In 2013, it launched an EU-wide strategy from micro- and nanoelectronics components and system where the ECSEL and IPCEI programs were introduced and ELG and RTOs were established. Nowadays, the European Union and Member States are working on the Horizon Europe Program promoting research and innovation with a budget of US$115.67 bn (European Commission, 2018). They also released the "Sustainable & Smart Mobility Strategy" to help stimulate the automotive industry in Europe, which will positively impact the semiconductor industry as the demand for semiconductor products will increase (European Commission, 2020b).

The focus on European investments and standards are mostly for traditional sectors, such as the automotive industry. European companies are key players in this industry. Those investments will give them the opportunity to progress developing advanced technologies and keep their international position. However, as the level of investments for other sectors in the semiconductor industry by European institutions, governments and companies is low, European companies in those sectors are not able to develop an international competitive position.

Also, due to disparities among Member States, standards established by the European Commission have a lower efficiency. First, the requirement of a second level of approval from the European Commission above the national level slows down the decision-making process. Furthermore, Member States don't have the same resources in order to apply standards in their home country (Kearney, 2020).

Throughout Five-Year Plans, the Chinese government has emphasized on the importance of the high-tech sector and the Chinese semiconductor industry. It implemented several plans, guidelines and strategies such as "the medium- and long-term plan for Science and Technology", the "Made in China 2025" and the "Guidelines to promote a national IC industry". Since 2011, the Chinese government has also been providing financial incentives, amounting at US$100 bn, in order to push semiconductor companies to increase their manufacturing expenditures.

Nevertheless, while making the analysis on governmental aids and incentives and comparing them, I realized that there is a lack of transparency and clearness. All governments are providing aids to their companies through different ways, making it difficult to conduct an accurate comparison. Based on this observation, it is difficult for me to provide a conclusion about the effectiveness of the different governmental aids.

5.5. The cooperation and collaboration inside an economic entity

The cooperation and collaboration level inside an economic entity is needed to the efficient development of an industry. Indeed, people, companies and national institutions will work together for common goals.

The United States is one single country with one market entity and one decision-making power, hence, the level of cooperation and collaboration is high. The same applies even more so for China as the Chinese government has a strong influence on private investments and provides a strong support to its companies (Conrad & al., 2016).

On the other hands, despites its institutions, the European Union is highly fragmented with several decision-making units represented by each national government and European institutions. Indeed, the decision process is slowed down by the requirement of the second level of approval from all the different governments. Also, European companies making business in Europe face different national regulations and standards in order to enter in another Member State's market. This can be compared with Chinese or US companies doing business in their home country; they benefit from one big single market without having to comply with different regulations.

Also, as mentioned in the defense industry, European countries don't always gather their investments in order to work on common projects. Indeed, Member States sometimes invest separately in the same projects. Consequently, European companies end up competing with each other instead of working together and be more efficient in order to be as stronger as the US and Chinese companies.

To illustrate this, table 4 shows the GDP of several countries, representing the resources of the different countries. Germany's GDP, which is the highest in Europe, represents only 18,16% of the US GDP and 25% of the Chinese GDP. Interestingly though, the European GDP which is the sum of all European Member Sates GDP, is bigger than the one in China and closed to the US GDP (IMF, 2020).

Table 5: the GDP per country in 2020 (IMF, 2020)

Countries	**GDP in US$ bn in 2020**
The United States	US$20,810 bn
China	US$14,800 bn
Germany	US$3,780 bn
UK	US$2,640 bn
France	US$2,550 bn
Europe	US$20,440 bn

5.6. The dependency level on foreign countries

The worldwide semiconductor industry represents a global ecosystem. During the production process of a semiconductor product, several countries are involved making them interdependent. However, some countries are more dependent than others.

A good indicator of the dependency level of one country against another is the level of exportations and importations. If a country is importing a great quantity of one product, it shows that the country is dependent towards this product. In the opposite way, if a country is massively exporting one product, it means that it is independent from others for this product.

According to the OEC statistics (2020), the US was a net exporter of Integrated Circuits[16] in 2018 (Appendix 3) exporting US$37.1 bn while importing US$26.1 bn, representing a trade surplus of US$1.1 bn. China and Europe were net importers with trade deficit of US$42.1 bn and US$7.8 bn respectively.
If we compare with the situation in 2010 (Appendix 4), the US trade surplus was about US$18.4 bn while China and Europe were still net importers in the sector. However the Chinese trade deficit was bigger amounting at US$60.7 bn. The European trade deficit remained almost the same during the years as it amounted at US$8.8 bn in 2010. (OEC, 2020)

[16] Integrated Circuits comprises all products with the HSN code 8542 which means Integrated Circuits and microassemblies (OEC, 2020)

Those figures show that, in 2018, the Chinese ICs industry was the most dependent one among the three as it had the highest trade deficit. However, as the Chinese trade deficit decreased during the years, China also reduced its dependency on other countries in the sector. On the contrary, the US ICs industry decreased its trade surplus by US$17.3 bn.

Nevertheless, it is not mentioned if the imports and exports coming from and to China represent products from Chinese headquartered firms or all firms located in China. As we know that 70% of chips manufactured in China are made from foreign companies (van Hezewijk, 2019), the numbers could have intrinsically different meanings.
Moreover, those numbers were gathered in 2018. As trade tensions in the semiconductor industry have risen during the past two years, it could be interesting to have a look at the same numbers for 2020 and analyze them. Unfortunately, it appears to be difficult to find export and import data, especially for the comparison between different countries, as they do not always involve the same range of products.

Another indicator to measure the dependency level of one country to another in the semiconductor industry is the number of patents acquired by companies. As explained earlier, a patent is granted by a patent office (mostly national) in order to protect an invention developed by a company. If other companies want to use this invention or technology, they must pay for a license to the patent holder. Companies that have a high number of patents are less dependent. In the opposite way, companies that don't hold any patent have to pay for the permission to use technologies of other companies, which by definition makes them more dependent.

As I developed earlier, semiconductor companies that own patents are mostly from the US. IBM, Intel and Qualcomm are among the top 20 patent holders in 2020 (IFI,2020). In comparison, Chinese semiconductor companies do not have a high number of patents. To illustrate this, Huawei, who is the first Chinese company in the ranking, has 14,315 patents while IBM has 37,304.
This shows that Chinese companies are more dependent on the US technology. In Europe, Siemens is ranked number one of European semiconductor firms and 9th in the worldwide ranking. It owns 25,320 patents (IFI, 2020).

Finally, as part of the Chinese "Made in China 2025" strategy aiming to become self-sufficient in the semiconductor industry in next several years, Chinese companies have increased their M&As from 2014 to 2018 by 18% per year (Chen & al., 2019). This increase in M&As targeted technological transfers mostly from US and European companies. This shows that the growth of the Chinese semiconductor industry is, to a certain extent, dependent on foreign companies and their technologies. Nevertheless, US and European firms undergoing M&As and joint ventures with Chinese companies can also benefit from an easier access to the Chinese market (VerWey, 2019). This will be discussed further in the report.
However, due to the increasing concern of the European Commission and the US government for Intellectual Property theft, the number of M&As from China has stabilized since 2018 (Congressional Research Service, 2020). Furthermore, the value of Chinese FDI transactions in the semiconductor industry has decreased by 33% between 2018 and 2019 (Arcesati, Hanemann, Huotari & Kratz, 2020).

5.7. The level of control and restrictions to foreign competitors

Controls and restrictions put in place by federal or regional institutions are there to protect the national or regional market from aggressive foreign competitors.

Due to the rise of geopolitical tensions between the US and China, both governments have increased their controls and regulations in order to protect their market. The US have established the Entity List and has been continuously increasing trade tariffs against several foreign products.
In response, the Chinese government has also released an Unreliable Entity List and tightened controls on exportations (Bicheno, 2020). It also established a new Cybersecurity Law that foreign companies must comply to before making business in China (Lewis, 2020). However, this new regulation lacks transparency and clearness allowing space for self-interpretation.

In 2018, the European Commission also started to keep an eye on M&As coming from Asian countries and had also put in place several standards to protect its market. The Cybersecurity Act in force since June 2019 is one of them. This regulation has established, among others, an

EU certification framework for ICT digital products, services and processes. It is based on specific European requirements such as comprehensive set of rules, technical requirements, standards and procedures (European Commission, 2020d). The aim of this certification is to enhance the cyber resilience of ICT products in EU and thus foster the EU Digital Single Market (Demircan & Kysela, 2019). As consequence, every foreign companies willing to sell ICT products, services or processes within the EU have to obtain this certification first (Arampatzis, 2020).

However, the application of the standards is slowed down by the fragmented levels in the European Union, making it somewhat inefficient. Indeed, most of the time, the European Commission provides a general framework and Member States are responsible to implement the standards in their country. However, European governments don't dispose the same resources and infrastructures to apply those standards which means the overall implementation is slower (Eddy, 2020).

5.8. The level of universities and workforce

The semiconductor industry is a knowledge-intensive industry as it continuously requires researchers to sustain a high innovation level. Companies with a high level of skilled and talented workforce will develop a competitive advantage against others.

The level of skills and knowledge of the semiconductor workforce of a country can be analyzed through the level of national engineering and technology universities. Looking at the top 25 universities of engineering and technology in the world rated by QS (2020), there are the same amount of US and European universities which is about eight. The two first universities are MIT and Stanford University, both located in the US, followed by the University of Cambridge in the UK. Most of the European universities in the top 25 ranking come from the UK, Switzerland and the Netherlands. Only two Chinese universities are in the top 25, namely the Tsunghua University and the Peking University.

Another factor that could impact the level of skills of employees is by looking at the international movements of workforce. Through the Global Talent Competitiveness Index

(GCTI)[17], we can analyze which country is able to attract the most talents. According to an analysis of KDM Engineering on the GTCI's 2019 report, the UK is the third country in the talent attraction ranking, followed by the US. The top 20 regroups, eleven European countries such as the Netherlands, Belgium, Germany and France (Withers, 2020).

Moreover, the number of graduate students is currently the highest in the US. According to OECD, among those students, the US counts more than 940,000 students enrolled in a master's in Engineering or Science program. In Europe, the country with the highest number of students in the same field is France with 298,930 students followed by Germany (OECD, 2020).

We couldn't find available data on the talent attraction capability of China which makes the analysis about the level of skills of Chinese workforce in the Chinese semiconductor industry difficult. However, an analysis in several years will be interesting as the OECD forecasts an increase of 300% of Chinese graduated students by 2030. 60% of STEM graduates will be from China and India, 8% will be European and 4% from the United States (OECD, 2020).

5.9. The access to the Chinese market

The Chinese market represents 60% of the global demand of semiconductor products in 2020 (Craig, 2020). Currently 20% of this demand is fulfilled by Chinese headquartered companies and 80% by foreign firms having at least one subsidiary in China.
According to an analysis from van Hezewijk (2019), the eight largest semiconductor suppliers in the world (which are mostly US companies) are selling more on the Chinese market than on the US market (Appendix 5).

This gap between the Chinese production and demand benefits foreign companies that can take over this market share. For example, 67% of Qualcomm's revenue come from China, such as Micro Electronics with 57% and Broadcom with 49% (van Hezewijk, 2019).

[17] The GCTI ranks countries based on their ability to grow, attract and retain talents in their country. Launched in 2014, it is based on 70 indicators and include 132 countries (GTCI Study, 2020)

However, with the geopolitical tensions between China and the US, it is possible that US firms will have to cut their business relations with Chinese companies. This could cause a decrease in the revenue of US semiconductor firms. However, it is currently too soon to make any conclusion.

Having some lack of technological knowledge, this situation also benefits Chinese companies. Indeed, foreign companies that enter the Chinese market, must comply with Chinese standards and regulations. This eases, to a certain extent, the technological transfer from foreign companies to Chinese ones. Also, as foreign companies employ Chinese workforce, Chinese employees can benefit of knowledge transfers.

While looking at European companies, NXP Semiconductors also sells more to China than to the US, representing 44% and 14% of its revenue, respectively (van Hezewijk, 2019). Most of Infineon's revenue comes from China, which represents 35% of its total revenue and increased by 7% between 2018 and 2019 (Infineon, 2019).
Also, as many foreign firms are located in China, European companies can benefit from high-tech industrial clusters and the presence of other foreign high-tech companies (Arcesati & al., 2020).

5.10. Conclusion on the effectiveness and relevance of each factor

After covering the different factors and the way they are carried out in a country, we can conclude on each factor's effectiveness and importance in the development of the semiconductor industry of one country.

Firstly, the demand from the defense and military department is undeniably a good way to foster the semiconductor industry and push for more R&D investments. However, it is not a prerequisite in the development of a company in the semiconductor industry. Semiconductor firms can find other incentives in order to expand their R&D investments.

Network effects and the innovation cycle are factors that positively impact semiconductor companies. Indeed, European and US companies have had their revenues increase. However, the semiconductor industry is continuously improving, and emerging technologies are entering the market. This means that there will be new opportunities to take advantage of network effects and innovation cycles.

It appears that internal R&D investments by companies are highly effective for maintaining a fast-paced innovation level required by the semiconductor industry. Companies investing sufficient amounts in R&D are able to stay competitive on the semiconductor market. Also, investments in manufacturing equipment are also important in order to increase the number of fabs in the country and be able to produce state-of-the-art semiconductor products. Accordingly, Chinese companies have the highest growth rate and invest the most for building new fabs compared to the two other regions. Nevertheless, US companies have been present on the market for longer than Chinese companies and have been able to collect a large number of patents due to their early investments.
The European investment levels in both R&D and for the manufacturing equipment are too low regarding the expenses required in order to stay competitive in the semiconductor market. However, the European environment provides sufficient laboratories and research centers to develop innovative semiconductor products.

As the semiconductor industry requires increasing expenses from companies in order to sustain the growth rate of innovation and the building of new fabs producing the latest advanced technologies, aids from governments and regional institutions are necessary. They alleviate the financial burden of those companies, protect the national market from foreign competitors and offer a beneficial environment for the development of semiconductor companies. Those aids are made throughout several ways; financial incentives from public administrations to semiconductor companies and national research departments in the semiconductor industry as well as implementations of programs, standards and regulations. Although the aims of those aids and incentives are the same among the three regions, the amounts and the ways are verry different from one country to another. Moreover, semiconductor companies across the different regions face different needs and challenges. As consequence, we can conclude that aids and incentives from governments and institutions are beneficial to the development of their semiconductor companies however it is complicated to affirm which way is the most efficient.

The high level of collaboration and cooperation inside an economic entity is highly important to achieve effective strategies, standards and regulations implemented by decision-makers. Decision-making processes are faster, and companies face a single home market which facilitate their development. With this in mind, the European Union is lacking collaboration and cooperation among Member States. Semiconductor companies have thus to comply with different national jurisdictions inside the European Union which increases their costs. Also, facing different national markets among the European Union increases the competition among European semiconductor companies. Member States should on the contrary gather their resources in the semiconductor industry together in order to properly compete with China or the US.

In addition, when a country is dependent on other countries, it could easily put the country in a disadvantageous position on the market. As the figures showed, European semiconductor companies are mostly dependent on the Chinese and US companies and technologies. China decreases its dependency on other countries in the semiconductor industry over time thanks to technological and knowledge transfers from foreign leading firms in the sector. As consequence, we cannot affirm that the development of semiconductor companies will be slowed down by their dependency level on foreign firms. However, as the dependency level of one country to another could be explained by several factors, the present figures are not sufficient in order to provide a conclusive analysis.

With growing trade tensions between the US and China, controls and restrictions imposed on foreign companies seem to be effective in order to protect a market. However, we will be able to analyze the consequences of this factor after a few years. Although, we can still point out that European Commission has some difficulties protecting its semiconductor market. Indeed, the standards provided by the European policy makers are not as effective as they should be for each Member States.

If we look at the influence of a skilled workforce, we see that although the US and Europe have good universities in Engineering and Science, China is growing in this sector. However with the current high level of international migration and a lack of precise data, we cannot prove that there is a direct link between the level of education and the number of skilled engineers in the semiconductor industry of one country.

Finally, the access to the Chinese market appears to benefit both foreign and Chinese companies. Indeed, Chinese semiconductor companies are currently not able to supply the increasing Chinese demand for semiconductor products. As consequence, foreign companies take this opportunity to fulfil this demand and increase thus their market share in the semiconductor industry. With an increasing number of foreign semiconductor firms located in China, technology and knowledge transfers to Chinese semiconductor companies are easier.

PART 3: Recommendations to US, European and Chinese semiconductor industries

In this part, I give some recommendations that could help the United States, China and the European Union improve their semiconductor industry. I propose relevant advice for the three regions on the basis of the comparative table and the conclusion I made on the most relevant characteristics of a semiconductor industry. I also take into consideration the current environment where companies are growing, and their future expectations.

1. The need to increase governmental aids to US semiconductor companies

In the framework of the 'America First' policy from the Trump administration, the US government highlights its willingness to relocate US semiconductor companies that are currently located in China (BDI, 2020). This objective implies high cost for US semiconductor companies. First, as most of semiconductor manufacturing facilities are located in Asia, there is a need to build new fabs in the US. Also, US semiconductor companies will have to endorse the increasing labour cost compared to China. In this way, the US government has to establish a national manufacturing plan for its semiconductor industry (Ferry, 2020).

Therefore, the US government should increase their incentives and aids directed at companies. Nowadays, according to the data I collected, the US government provides merely US$5 bn per year to semiconductor companies. A higher level of financial aids could decrease the overall cost that US semiconductor companies will have to bear to change location. It will also provide relevant incentives for US companies to relocate instead of depending on revenues generated by the Chinese market.
Reducing the financial burden of US companies will encourage them to increase their investment in building new factories in the US in order to manufacture their products there. Currently, the level of investments in building manufacturing from US companies is too low compared to China.

According to a report made by SIA, federal incentives valued at US$50 bn in 2020 will have the possibility to create 19 major semiconductor manufacturing facilities which could cover the demand of semiconductor products from the US defense and aerospace industries (Goodrich, Varadarajan, Varas & Yinug, 2020). Also, these incentives will create 70 000 high-paying jobs in the US over the next 10 years which will increase the number of US semiconductor skilled workers. (Ioannou, 2020).

However, as the initiative to support the relocation process of companies is quite new, it could be interesting to examine the situation in a few years from now. We will be able to provide a more objective analysis on the outcomes of the governmental decisions made nowadays and provide more adapted advice.

2. The need for more cooperation and collaboration among the European Union

Illustrated by the fragmentation of European standards and the low decision-making process, the effectiveness of the Single Market in the European Union is weak. This implies disparities and divergences within European industries and Member States. This is mainly due to a low level of cooperation and coordination among EU Member States. A higher level will give the opportunity to Member States to pool their resources together such as their financial strength, skills and knowledge. In this way, European research centers and laboratories could closely work together instead of competing against each other. Building one single entity could give the European Commission more consistency when establishing international trade agreements with other countries. It could also give European semiconductor companies the ability to be stronger when facing worldwide top leaders in this industry.

In fact, a well-integrated Single European Market (SEM) where European companies are pooling their knowledge and resources together in order to work on common projects will increase the productivity of companies in this industry. Companies will be able to improve their investments level (Micossi, 2016). Those investments will have more weight, more impact and they will be more efficient and effective. The current level of investments in R&D and in manufacturing equipment from European semiconductor companies is low, compared with the Chinese and US levels and hampers the development of the European semiconductor industry. An increase in those types of investments could be beneficial for the European semiconductor companies as it will increase their technology capabilities and decrease the European technological dependence on other countries.

In terms of standards, the implementation of legislation is uneven across countries because Member States don't dispose of the same resources and tools useful to an efficient application of European regulations. Also, some standards are not adequate to all Member States and tend to increase regulatory fragmentation among the Single European Market. This hampers European business to expand in Europe.
A common set of standards applied to every Member State will also faster and easier decision-making process from European institutions and Member States. Consequently, the European Commission will be more able to protect its market from non-European competitors. Increasing controls and restrictions to foreign semiconductor companies when doing business in Europe will offer more opportunities to European businesses to develop and grow. European semiconductor firms are currently leaders in their niche markets. If the European market is more protected against foreign enterprises, European companies could keep their leading positions in those markets. In addition, they might be able to attract a significant market share for the emerging technologies such as AI and 5G.

This high level of fragmentation in the European Union is mainly due to disparities among Member States. First, cultural differences and linguistic barriers hamper the collaboration and cooperation among European policy makers (Kearney, 2020). Also, no sufficient support is provided by Member States to the establishment of the Single European Market. Indeed, some national policies and regulations hamper the integration of the SEM (Micossi, 2016).

However, as European semiconductor companies suffer from trade tensions between the US and China, it is safe to say that Member States will increase their collaboration and cooperation among the European Union regarding their semiconductor industries. Indeed, the US restrictions imposed to Chinese high-tech companies induce that European semiconductor suppliers have also to apply for the US license in order to chip products to China. In the car industry more specifically, European companies rely on US technology for the manufacturing of new smart and autonomous cars while the biggest demand for those products is in China.

If European companies are obliged to only partner with one of the two countries, they will lose market share in this sector. As European semiconductor companies feel insecure in this bilateral confrontation, European governments have stated that they want to decrease their dependency on foreign semiconductor products and technologies (Yang, 2020). Therefore, in December 2020, 18 European countries have signed a commitment to invest up to US$177 bn (€145bn) in the next two or three years to boost the European semiconductor industry. Taking part of the IPCEI framework, this joint initiative aims to improve cooperation among Member States and increase investments in the European semiconductor industry (European Commission, 2020b).

Future analysis will tell us the efficiency of this joint commitment in the development of the European semiconductor industry.

3. The need to increase market share in emerging technologies

Regarding the comparative analysis and the conclusions I made on the effectiveness of key characteristics of a semiconductor industry, the Chinese semiconductor industry appears to be in a good position.

Since the beginning of the century, the Chinese government has established aggressive strategies to catch up with top leaders in the semiconductor industry. Most importantly, they have longer term plans to become self-sufficient in this industry. To this day, those strategies appear to be effective as the Chinese semiconductor industry shows a high growth rate and a good perspective for the future.

In term of investments, the Chinese R&D investments level in the semiconductor industry don't equal the level of the US. However, it shows the highest growth rate compared to the US or the European Union. This future increase in R&D investment will enhance the ability for Chinese semiconductor firms to grant more patents and develop their own innovative products. Furthermore, Chinese companies invest the most in equipment manufacturing and rely heavily in M&As in order to increase technology transfer.

The emergence of new technologies offers the opportunity to Chinese semiconductor companies to increase their market share and thus benefit from economies of scale through network effects and innovation cycles. As such, the Chinese semiconductor industry will keep its growth rate and Chinese companies will be able to decrease their dependency towards more advanced countries in the sector. In the long-term run, Chinese headquartered semiconductor firms should be able to satisfy the national semiconductor demand which is one of the goals of the 14^{th} Five Year Plan released in October 2020. Indeed, the Chinese government wants to promote a “dual-circulation strategy” to stimulate domestic market circulations (Bicheno, 2020). Having this in mind, Huawei and Xiaomi already begun to produce their own chips (Lucas, 2019).

Current trade tensions with the US have pushed the Chinese government to take aggressive measures in order to protect and foster its semiconductor industry. Since a few years, more controls and restrictions have been added to foreign semiconductor companies willing to make business in China. Also, new strategies supporting the increase of self-sufficiency of Chinese companies towards foreign technologies have been established. As some consequences of those measures and actions will still appear in the following years, they should be analyzed in the future in order to provide a more comprehensive and objective conclusion on their efficiency.

Conclusion

In this thesis, I tried to figure out what are the key characteristics an environment should have that benefit companies in the semiconductor industry. I chose to make a comparative analysis on three economic units that are relevant in the semiconductor industry: the United States, the European Union and China.

In order to realize this analysis, based on literature review and factual data, I started by describing key characteristics found in every region, whether they were beneficial or not for semiconductor companies. It allows me to conclude that wherever a company is located, national governments or regional institutions are providing aids and incentives to their semiconductor firms in order to support their development and to help companies bear some of their cost. However, each government has their own way of operation; with different amounts and different methods. Moreover, investments made by semiconductor companies either in R&D or for the building of new fabs appear to be an inherent characteristic to the worldwide semiconductor industry but, each company deals with different amounts and for different purposes.

Regarding the US semiconductor industry, we can notice that they started their activities in the semiconductor industry thanks to the US defense and military industry and its need for innovative products. This allows US semiconductor companies to benefit from economies of scale in the sector. Furthermore, thanks to high level of US education since several years, the US semiconductor companies benefit from high skilled engineers and scientists to develop their products.
In the European Union, semiconductor companies are enduring a high level of fragmentation inside the region implying that companies don't benefit from the resources a large unified market could offer and have to comply with different national jurisdictions. Nevertheless, some European companies were able to secure a leading position in some niche sectors of the semiconductor market such as the automotive, security and healthcare industry.
The Chinese semiconductor market represents strong advantages due to its low labour cost and its ever-increasing demand for semiconductor products. Indeed, 57% of the worldwide

consumption of semiconductor products happens in China (Pwc, 2019). The Chinese government also imposes strong controls and restrictions to foreign companies in order to protect its market.

Afterwards, I compare the three chosen regions based on every characteristic developed earlier. I could then conclude on the most effective ones that allow semiconductor companies to grow and thrive in the market. We can count four characteristics that are undeniably relevant for the development of semiconductor companies in their markets: investments made from semiconductor companies themselves, protection tools provided by national or regional governments, the access to the Chinese semiconductor market, and a high level of cooperation and coordination inside the national or regional semiconductor market. I will develop those in the next paragraph.
Two other factors: the demand for semiconductor products coming from the military and space industries, and the access to economies of scale through network effects and innovation cycle are also benefiting the development of semiconductor companies. However, they do not seem to be prerequisites. Indeed, there exist other ways to foster the demand for semiconductor products and semiconductor companies can still reach sufficient economies of scale by targeting emerging technologies. Regarding the last factors present in the comparative table such as aids and incentives from government to the semiconductor industry, the level of dependency of one country to another, and the level of talented workforce, I can't make any conclusion as data lack transparency and clearness, aren't reliable or the appropriate data were not found.

The investments from companies in either R&D or manufacturing equipment are important factors. Indeed, they have shown to be effective in the development of the companies in the semiconductor industry. US companies have the highest R&D spending and the most granted patents. Although Chinese companies have the lowest percentage of R&D investments among the three regions, they also have the highest investment growth rate in ICT. However, European companies have the lowest level of investment, but the European Union fosters a good environment for R&D as it counts several research centers and laboratories.

In term of investment in manufacturing equipment, Chinese companies have invested the most in the recent years compared with the two other regions. Consequently, the production of semiconductor products has increased drastically.

The second factor that appears as effective for the development of a semiconductor company in its market is the protection tools put in place by the government. Indeed, controls and restrictions imposed to foreign companies provide more space to national semiconductor companies to grow in their market. It is particularly true for Chinese semiconductor companies as the Chinese market is highly attractive for foreign companies. However, regulations imposed by the US, China or even the European Union increase since the past few years with the rising of geopolitical tensions between the US and China. As consequences, it should be interesting to analyze in the near future the actual effectiveness of those new restrictions.

Regarding the access to the Chinese semiconductor market, data are showing the importance to have a free access to this growing market. The demand for semiconductor product in China represents 60% of the worldwide demand (Craig, 2020) and Chinese companies are currently only providing 20% of this demand. This represents a great opportunity to fulfill for foreign companies. Also, Chinese companies are benefiting of the presence of foreign companies in their country as it facilitates technology transfers.

Looking at the level of fragmentation of the European market that companies have to face, we can conclude that the lack of cooperation and coordination is a real obstacle to European companies in their development inside the European semiconductor market but also internationally. The absence of a unified market with one single decision-making unit implies a slower responsiveness in the market. Also, the absence of shared resources makes them ineffective while competing with international semiconductor leaders.

Afterwards, I develop some recommendations for the three regions in order to improve their semiconductor industry. I based those recommendations on three factors: the conclusion made on the effectiveness of key characteristics present in an environment for the development of semiconductor industry, the current environment where semiconductor companies are evolving and the future expectations of each region for their semiconductor industry.

Regarding the position of the US semiconductor industry and the willingness of the US government to relocate its semiconductor companies in its country, the US government should increase aids and incentives provided to US semiconductor companies. This will decrease the financial burden of companies and encourage higher investment in the building of new fabs in the US.

The greatest obstacle in the development of the EU semiconductor industry is the lack of efficiency of the Single European Market. This could be fixed with a greater level of cooperation and collaboration among Members States, which is even more needed due to the increasing tensions between the US and China. Companies will be able to gather their investments in order to facilitate the competition with international semiconductor leaders. Also, it will simplify the establishment of common European standards and regulations in the sectors which could increase the protection of the European semiconductor market against foreign competitors.

The Chinese semiconductor market sustains a high growth rate thanks to strong strategies coming from the Chinese government and the increasing level of investments made from Chinese semiconductor companies. This improves technology transfers and decrease the dependency of the Chinese semiconductor industry towards foreign ones which is the target of the latest FYP. Chinese companies have to cease the opportunity to increase semiconductor market share while emerging technologies arrive on the market. As such, they will benefit of economies of scale in this sector. This will secure the Chinese growth rate in the semiconductor industry in order to catch up with more advance semiconductor industries.

Limits and further researches

The scope of this report only targets a comparison between semiconductor industries of the United States, China and the European Union. Adding more countries that are active in the sector, such as South Korea, Taiwan, and Japan could have been interesting for the comparative analysis. As their companies have succeeded and some of them are among top leaders in the industry, it could help detect additional factors to the analysis.

Also, this report is mostly based on information and data provided on the internet or in books. This information sometimes lacks clearness or is simply undisclosed, such as the investments made from governments to their semiconductor industry. Furthermore, data regarding the targets, the amount and the impacts that such investments have on the industry are difficult to find and most of the time are not comparable between the three regions. An easier access to data could have brought more insight to the analysis.
Moreover, after having done a personal interview with M. Glinos (Appendix 6) in which I asked several open questions, I realized it wasn't the kind of information I needed to conduct my research. Indeed, I wanted to base my results on factual data and figures which wasn't what I collected through the interview. Therefore, I chose not to collect information through personal interviews. However, if sufficient amount of data were collected from experts in the field, it could have brought a deeper understanding of the semiconductor industry and the way it is organized.
Nevertheless, the interview allowed me to understand I was in the right direction and it helped me develop recommendations that I included in the last part of my thesis.

As we are at the core of the trade tensions between the US and China, the semiconductor industry will be prone to many changes in the way business is done as well as in the way value chain is organized. The covid-19 pandemic will certainly have an impact on the interdependence of countries (Custer, 2020). Companies will have to reinvent their business model and figure out new ways of competing internationally. Moreover, the European Commission has finally reached an agreement with the UK concerning the Brexit that will also affect business' organizations inside the European Union. For that, it could be interesting to make further researches in the near future to analyze the consequences.

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