Politecnico di Milano

School of Industrial and Information Engineering

A Secondary Sources Analysis of the Business Models and Supply Chain Strategies of Semiconductor Manufacturers

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Abstract

The present work studies the business models and the supply chains of the semiconductor industry, and their relationship. More specifically, this work is supposed to investigate whether the business models and related supply chains have adapted to the structural changes brought by the continuous innovations in semiconductor field.

This analysis, first deliberates the main features of the industry, analyzing the general structures, the main semiconductor applications and the future trends; then evaluates the specific business models and supply chains, to understand which is the best suitable supply chain for each business model.

The business models analyzed, show two different configurations, the Integrated design manufacturer model (highly vertical integrated) and the Foundry model, that relies on a network of enterprises, outsourcing many production processes.

From preliminary findings, the “Agile” supply chain has emerged as a dominant strategy for semiconductor producers. Hence, the integrated design manufacturer model which was historically considered the industry cornerstone, is now facing increasingly difficulties, being by structure more tending to a responsive supply chain.

In addition, Intel Corporation and Xilinx have been further examined to get more insight into two of the world’s largest semiconductor companies.

In the end, we have tried to shed some light on the emerging trends and how they are going to affect the two supply chains in future, especially, focusing on process efficiency as a key force.

Keywords: Semiconductor industry, Supply chain, Business model, Integrated design manufacturer, Fabless-foundry, Integrated Circuit.

Acknowledgements

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Firenze, July 2021

Filippo Olivieri

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Abbreviations

AI Artificial Intelligence

ADAS Advanced Driver-Assistance Systems

AP application processor

ASIC Application-Specific Integrated Circuit

ATP Assembly Testing & Packaging

BSG Boston Consulting Group

CAD Computer-Aided Design

COT Customer Owned Tooling

CPUs Central Processing Units

DAO Discrete, Analog, and Other

DRAM Dynamic Random- Access Memory

EDA Electronic Design Manufacturer

EMS Electronics Manufacturing Services

FAB Semiconductor manufacturing facilities

FPGAs Field Programmable Gate Arrays

GDP Gross Domestic Product

GPS Global Positioning System

GPUs Graphics Processing Units

IC Integrated Circuit

IDM Integrated Device Manufacturer

IoT Internet of things

IP Intellectual Property

IPR Intellectual Property Rights

LED Light Emitting Diode

KSF Key Success Factor

MCUs Micro Controller Units

M&A Mergers & Acquisitions

MOSFET/ MOS transistors Metal-oxide-semiconductor field-effect transistor

NPD New Product Development

ODM Original Design Manufacturer

OEM Original Equipment Manufacturer

OLED Organic Light Emitting Diode

OSAT Outsourced Semiconductor Assembly And Test

OTD On Time Delivery

PESTEL Political, Economic, Social, Technological, Environmental, Legal

PWC PricewaterhouseCoopers

R&D Research & Development

RF Radio Frequency

SCPA Semiconductor Chip Protection Act

SIA Semiconductor Industry Association

SoC System on Chip

SD Secure Digital

SSDs Solid State Drives

TCO Total Cost of Ownership

TSMC Taiwan Semiconductor Manufacturing Company

1 Introduction

1.1 Background

The semiconductor industry became a viable business around 1960. Until then all electrical components had been discrete; they could only perform one function and many of the components had to be wired together to create a functional circuit. With new technology, Integrated Circuits (ICs) were developed with multiple components put together on the same chip (Joakim Nideborn and Kristina Stråhle, 2007).

There are a few materials that are classified as semiconductors. The most well-known is silicon, but there are also other elements and chemical compounds that are semiconductors, for example germanium or aluminum gallium arsenide. Semiconductors have the ability to conduct electrical current and they can be regulated in the amount of conductivity. (Hartmut Stadtler & Cristoph Kilger, 2004).

The semiconductor industry has developed enormously since 1960 and today it is one of the world's key industries. The rapid development in the industry results in massive Research and Development (R&D) costs with 15-30% of the net sales spent on R&D (Antonio Varas *et Al*, 2021).

With the great amount of capital required to sustain continued miniaturization, the semiconductor industry is faced with a standpoint and to minimize the costs and risks of R&D many companies create alliances and collaboration networks.

To understand the innovation spread that has taken place for 20 years now, today it is possible to produce chips with 3-nm process node technology

(https://www.anandtech.com)

The Integrated Device Manufacturers (IDMs) are now considering cutting down on in-house manufacturing by outsourcing the production, due to the growing pressure coming from Fabless-foundry companies.

1.1.1 Importance of the semiconductor industry

Semiconductors are the Brains of Modern Electronics.

Semiconductors are an essential component of electronic devices, enabling advances in communications, computing, healthcare, military systems, transportation, clean energy, and countless other applications, indeed "The semiconductor supply chain is the backbone of the digital economy" (Antonio Varas *et Al*, 2021, Page 8).

Due to their role in the fabrication of electronic devices, semiconductors are a crucial part of our lives, enabling technologies critical to countries' economic growth, national security, and global competitiveness. Imagine life without electronic devices. There would be no smartphones, radios, TVs, computers, video games, or advanced medical diagnostic equipment, enabling the semiconductor industry to acquire a crucial role in the world political equilibrium (Erik Pederson *et Al*, 2020).

Without semiconductors, the technology that we count on every day would not be possible. Semiconductors are all around us.

To really understand the semiconductor industry importance, just think about the semiconductor shortage that began in 2020, which is still slowing down the whole automotive supply chain.

As the building blocks of technology, semiconductors will continue to enable the world's greatest breakthroughs.

1.1.2 Business model

A business model can be defined as a company's architecture of value which explains how the company first generate value for the customers, and secondly capture a part of this value to sustain it (Grant,1991).

The business model definition, comes after the definition of the strategic alternatives. Each strategic alternative has its own business model. So, the business model is related to the strategy implementation and execution.

This tool, is commonly used to understand the process of value generation and how companies are able to capture the value generated, making clear which are the strategic factors that are needed in the strategy implementation.

Today, business models themselves become an object of innovations, since they are enablers to achieve successful innovations.

1.1.3 Supply chain

Supply chain is one of the most relevant topic in the portfolio of the managerial activities.

Supply chain is generally definable as: "a network of facilities that produce raw materials, transform them into inter-mediate goods and then the final products, and deliver products to customers through a distribution system" (Johnsen *et Al*; 2014).

In addition, today in not enough keeping in internal perspective in order to compete in a global arena. The more the world becomes interconnected, the more supply chains acquire importance, due to their strategic role, in cost saving and in value delivering to the final customer.

Furthermore, a well-managed supply chain, lead to have a competitive advantage in the market, delivering a higher value to the customer.

1.1.4 Business model-supply chain relation

A supply chain encompasses many value added activities performed by a company, clarifying the strong connection with the company's strategy, that has to draw a coherent supply chain, in order to maximize the company' value.

Indeed, when identifying a strategy, we identify two outputs: the shape of the supply chain and the set of managerial actions.

The link between these two concepts is really important, because the visibility, the processes must be designed and managed at a network level, not a single node level, companies need to be aware that actually we are part of a network of interconnected firms. We need to manage the processes going beyond the boundaries of the firm, because optimizing the internal processes is no longer enough.

Moreover, the competition is among other supply chain as a "whole" not against individual companies.

1.2 Problem discussion

The present work, tries to discuss the semiconductor companies profitability over time, due to the high development cost of new production technology it is not certain that the same companies with the same business models exist in the market five years from now. In a such fast changing industry, a fundamental feature is the adaptability of the company to the context.

Being aware of the semiconductor industry importance and complexity, the scope of this thesis, is to study the characteristic business models of the industry and their implementation in the supply chains, in order to understand the key success factors that enable companies to be sustainable and profitable overtime. At the beginning, I was interested in understanding the complex business models used in this industry and their relative implementation in the supply chain. Indeed, the core body of the thesis relies around two main research questions:

- **1° Research question:** *How are semiconductor manufacturers business model organized?*
- **2° Research question:** *How are they implementing their business models into supply chains?*

The aim is to capture, how the different business models implements their supply chains, to be able to be consistent with their business model strategic choices.

1.3 Expected results

Since the semiconductor industry is developing fast and also due to the fierce competition, more and more companies seem to be acquiring new competencies and broadening their business area. As in many other industries also in this sector, following the standard supply chain framework, semiconductor companies are expected to go in the network of enterprises direction, creating strong relationships with the whole supply chain actors. Getting further and further away from highly verticalized structures, that are unable to cope with the semiconductor unstable environment.

The old structures of industry are decaying due to an increasingly less stable and ever-growing environment, that necessities flexibility and a strong relation between business model and supply chain.

As main results, I am expected to observe a transformation of the IDM business model, outsourcing the non-value added activities, in order to focus on their core competencies. Indeed, the network of enterprises have emerged, as the new key to survival, transcending geographical boundaries, accelerating the speed of product life cycles, and resolving the lack of resources. Firms that adopt the classical closed business model are responsible for the product concept, product design, product manufacturing, product marketing, and post-sale services, too many activities, no longer sustainable in semiconductor context. Indeed, through the division of work and integration at the global level, I'm expecting that consumers will be able to gain the maximum benefits, while the most competitive firms in each section of the value chain also benefit from the dramatic increase in their economies of scale and increased profit.

1.4 Target group and utility

This thesis is thought to be useful to all the semiconductor industry stakeholders, be their semiconductor companies manager, up-stream suppliers or down-stream customers. Indeed, People involved in the semiconductor or telecommunication industry could find it interesting to read the thesis work. Mainly, because the work tries to summarizes many information of the industry, in order to have a clear picture of the industry, that allow to make forecasts on the future development of the whole sector.

The second target for this document, could be the Politecnico students, that through this research could gain some basic knowledge about semiconductors industry. I recommend the reader to examine Chapter 4 very carefully as it provides a background to those with none or little knowledge of the subject.

In addition, this paper is to fill the gap between the business model and its implementation into the supply chain. Especially the study, goes through the supply chain nodes, analyzing which are the most value added activities, that need to be performed in-house, and on the contrary which are the ones to be outsourced.

2 METHODOLOGY

2.1 Sources research

In order to answer to the two research questions, the sources selected and used to perform the analysis are secondary sources, also for the difficulties of obtaining valid and reliable primary data in the semiconductor context. “Secondary data can be defined as data collected by others, not specifically for the research question at hand” (Christopher J. Cowton 1998, Page 424). In addition, secondary data not only offer advantages in terms of cost and effort, but also that in certain cases their use may overcome some of the difficulties that particularly afflict business ethics researchers in the gathering of primary data.

Indeed, the collection and analysis of primary data would have been too problematic an too long for a topic as the semiconductor industry analysis. So, one possible way forward is not to become embroiled in the difficulties relating to the collection of good primary data, but rather to use secondary data; that are, data that already exist (Christopher J. Cowton 1998).

Secondary data is all already existing material like literature and web based sources. This information is not generated specifically for the study and is therefore rarely covering the exact area of interest. When using this information it is very important to be critical to the contents and consider whether it is really vital for the subject.

2.1.1 Secondary sources:

I have adapted this methodology to study the semiconductor business models and supply chains, changing the disciplinary area of application of resources. Whatever the precise wording used, the essential point is that the researcher does not gather the data. Secondary data can take a wide variety of forms, as guides to bodies of collected data make clear. The following sub-sections divide secondary data according to certain broad categories of sources, that have been used in the analysis:

A. *Data from government:*

   Governments are important publishers of data, one of the best known forms being censuses. There are also many quasigovernmental and other official bodies which produce large amounts of data. In this analysis, government’s data have been fundamental since the semiconductor industry has a crucial politic role, that increases the government attention.

For what concern this thesis, the main sources of government' data have been:

- SIA (Semiconductor Industry Association);
- Center for Security and Emerging Technology.

B. *Data form companies:*

Companies are an important sources of secondary data. Much material is publicly available particularly in the annual report and accounts. Financial data derived from company accounts are now easily available in the form of public databases. The main limitation of this kind of data is that it is constructed at a "macro" level, regarding each company as a single entity (Christopher J. Cowton 1998).

In this work, data from companies have been very useful, due to the various company's reports. The main company' sources have been:

- Intel;
- ON semiconductor;
- TSMC;
- Xilinx Inc.

C. *Data from newspaper:*

Newspaper articles can, as well as providing timely and pertinent "vignettes" for teaching purposes (Bain, 1994). The "media" also include other useful material, mainly for what concern the last news. in In particular in the present work, newspapers have been very full of information, due to the global role acquired by semiconductor products, in the last year.

The main newspaper used, in the thesis work are:

- CNN;
- The Washington Post;
- Statista;
- Wikipedia.

D. *Data from academic research:*

The semiconductor industry topic, have been well analyzed by academic researchers. "One of the benefits of this is that it generates a larger effective sample than an individual study in isolation" (Christopher J. Cowton 1998, Page 424).

Research from two universities was used in this thesis:

- Fern Fort University;
- Lund University.

E. *Private source:*

Private sources have been very informative for this study, since companies' internal reports can provide good material.

"Sometimes is not easy to gain access to these sources, but since the interests of the researcher tend to be in the general rather than the particular, it can be relatively easy to reassure the relevant parties" (Christopher J. Cowton 1998, Page 426). In addition in semiconductor industry, there are many private sources, since work closely with government institutions.

The present research was able to gain access to these private sources:

- Accenture;
- BSG;
- McKinsey
- Deloitte;
- PWC.

What they have in common is that they have been collected by some other party, generally without the research purpose of the subsequent business ethics user in mind.

2.1.2 Data collection

Contemporary to the writing of the thesis, was made a data collection database on excel file, in order to keep track of the research process and the main pattern used to find the data sources. Below the explanation of the main data collection patterns:

2.1.2.1 Most used sites:

In order to grab the most reliable and precise information, the analysis relies mainly on these sites (alphabetic order):

- Accenture;
- Deloitte;
- Investopedia;
- McKinsey;

- SIA;
- Statista;
- The Washington Post;
- Wikipedia.

2.1.2.2 Key-words:

To let understand the relevance of the different research' words, below are shown the key-words used during the research phase. The analysis show the key-word' findings with their ranking position and last date of research, using a standardized format.

Standardized format of the research keyword' findings (Ranking position; Last date of research).

Key-words:

(a) Semiconductor industry (140.000.000 results):

(i) Semiconductor industry – Wikipedia (1° ranking position; 04/05/2021);

(ii) Semiconductor Industry Association (2° ranking position; 19/10/2020);

(iii) 10 Biggest Semiconductor Companies – Investopedia (3° ranking position; 22/03/2021);

(iv) Insights on Semiconductors – McKinsey (6° ranking position; 31/03/2021);

(b) Semiconductor applications (230.000.000 results):

(i) semiconductor | Definition, Examples, Types, Uses, Materials – Britannica - (1° ranking position; 15/04/2021);

(ii) About Semiconductors | SIA | Semiconductor Industry (10° ranking position; 19/02/2021);

(iii) Semiconductors – the Next Wave Opportunities - Deloitte (12° ranking position; 31/03/2021);

(iv) Insights on Semiconductors – McKinsey (6° ranking position; 31/03/2021);

(c) Pestel analysis semiconductor industry (214.000 results):

(i) Semiconductor Industry Case Study PESTEL Analysis (3° ranking position; 15/03/2021);

(ii) Intel SWOT & PESTLE Analysis | SWOT & PESTLE (8° ranking position; 11/02/2021);

(d) Automotive semiconductor shortage (5.820.000 results):

(i) Coping with the auto-semiconductor shortage – McKinsey (3° ranking position; 03/06/2021);

(ii) Automotive semiconductor shortage – The Washington Post - (9° ranking position; 19/05/2021);

(e) Semiconductor industry main players (8.690.000 results):

(i) Semiconductor Market Size & Share | Industry Growth [2028] (5° ranking position; 04/05/2021);

(ii) Top semiconductor companies 2019 | Statista (9° ranking position; 04/05/2021);

(iii) Semiconductor industry - Wikipedia (2° ranking position; 04/05/2021);

(iv) Top 10 foundry revenues expected to increase (8° ranking position; 21/03/2021);

(f) Semiconductor business model (44.600.000 results):

(i) What Are "Fabless" Chip Makers? - Investopedia (4° ranking position; 04/05/2021);

(ii) Fabless manufacturing - Wikipedia (3° ranking position; 15/03/2021);

(iii) The evolution of business models in a disrupted ... - McKinsey (7° ranking position; 22/03/2021);

(iv) Semiconductor companies - Accenture (6° ranking position; 31/03/2021);

(v) Analysis of Competition Between IDM and Fabless–Foundry (11° ranking position; 27/03/2021);

(g) Semiconductor supply chain (57.200.000 results):

(i) Strengthening the global semiconductor supply chain in an uncertain era – SIA -(2° ranking position; 04/05/2021);

(ii) A Look at Semiconductor Supply Chains – TSMC -(4° ranking position; 19/04/2021);

(iii) Semiconductor Shortage Shines Light On Weak Supply Chain (6° ranking position; 23/05/2021);

(iv) Quantifying the semiconductor supply chain | McKinsey (8° ranking position; 16/03/2021);

(v) Why We're in the Midst of a Global Semiconductor Shortage (11° ranking position; 01/03/2021);

(vi) Semiconductor Supply Chain Resiliency | Accenture (22° ranking position; 16/05/2021).

2.2 Source analysis: how do you have analyzed data?

There are different requirements to the theories that will be applied in this study. The theories cannot be too extensive concerning time consumption and should be easily applicable onto the existent situation. The theory frameworks should primarily facilitate the work, achieving the purpose of the study. The theories and the frameworks used, come mainly from the studies carried out in the master's degree.

Theories and frameworks (thesis order):

2.2.1 *PESTEL*: is a technique used to identify, assess and evaluate external factors affecting the performance of an organization with the aim of gathering information to guide strategic decision-making (Grant,1991). In the semiconductor industry analysis, assumes a fundamental role as the industry is heavily affected by external factors as politic and technological factors.

Pestel is useful, to distinguish the influences in the micro-environment it is possible to investigate the macro-environment with the help of a PESTEL (Political, Economic, Social, Technological, Environmental and Legal) analysis. In order to separate the important factors from the vital ones it is crucial to understand the connection between a PESTEL analysis and the value network described in sub-chapter 3.4. A reason for this is that the core of the company’s business environment comes from, and is formed by its relationship with its customers, suppliers and competitors. There are four factors that have a great impact on the semiconductor industry and these factors are: Political, economic, technological and legal factors.

2.2.2 *Osterwalder’s business model canvas*: The Business Model Canvas is a strategic management template used for developing new business models and documenting existing ones. It offers a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances, assisting businesses to align their activities by illustrating potential trade-offs (Grant, 1991). It is composed by nine building blocks:

1- *Customer segments:* represents your market;
2- *Value proposition:* it defines the products/services you are delivering to the customers;
3- *Channels:* how you relate your value proposition to your customers;
4- *Customer relationship:* they in which you manage your channel;
5- *Key activities:* what you perform;
6- *Key resources:* resources necessary to compete in the market;
7- *Key partners:* other actors, through which I deliver value;
8- *Cost structure:* capital expenditure and operating expenditure of the company;
9- *Revenues streams:* how a company's makes money.

2.2.3 *Supply Chain Map (Global supply chain model):* is the process of documenting information across companies, suppliers, and individuals who are involved in the company's supply chain, to create a global map of their supply network. Global means that we are dealing with company that are manufacturing or sourcing around the world (Johnsen *et Al*; 2014);

2.2.4 *FISHER analysis:* This framework specifies the two key uncertainties faced by the product—demand and supply. Fisher introduced the matching of supply chain strategies to the right level of demand uncertainties of the product (Johnsen et Al; 2014). Fisher prospective is an outbound one, it looks at the characteristics of the products as they are perceived by the final customers. It does not take into account the source and make phase, just delivery. The output of Fisher's model is the division of the products in two categories: Functional or innovative products;

2.2.5 *HAU LEE analysis:* classifies the companies according to the kind of customers, it analyses different issues related to the demand or manufacturing in terms of characteristics seen/perceived by customers and in addition it comprises also the supply side uncertainty. (Johnsen *et Al*; 2014). The result is the Lee's matrix that explicit four kind of supply chain strategies, according to the demand and process characteristics. The four supply chain strategies are:

- *Lean supply chain:* design in order to avoid waste;
- *Risk hedging supply chain*: strategy adopted to cope with instability of internal processes;
- *Responsive supply chain:* design in order to cope with customer's need variety;

- *Agile supply chain:* mix of strategies, to be flexible and to cope with up-stream and down-stream instabilities.

2.2.6 *Value chain:* represents the internal activities a firm engages in when transforming inputs into outputs (Grant,1991). A value chain is the context within which a firm exists, establishes an operation process and works with suppliers and partners in order to create value and so forth gain net sales of a prospect customer. Each company's strategy defines its ability to handle the threats and opportunities that come from disruptive versus sustaining innovation. The value network gives the macro-economic view of an industry. This method is used as it is rare for a single company to undertake all of the value creating activities of a product. That is why a company is part of the wider value network that creates the value from product design to the end customer. It is important for managers to understand what type of value network the company exists within as this creates a foundation for outsourcing decisions. By mapping the value network, the best partners and suppliers can be chosen and the type of level the relationship should be.

3 INDUSTRY OVERVIEW

3.1 Key figures

The semiconductor industry is widely recognized as a key driver and technology enabler for the whole electronics value chain. Indeed, semiconductors are a crucial element in modern electronics, making up an important component of many commonly used electronic devices, essentially all modern devices that many of us have become so highly dependent on in everyday life.

The industry became a viable business around 1960. Until then all electrical components had been discrete; they could only perform one function and many of the components had to be wired together to create a functional circuit. With new technology, Integrated Circuits (ICs) were developed with multiple components put together on the same chip.

The semiconductor industry has developed enormously since 1960 and today it is one of the world's key industries. MOSFET (metal-oxide-semiconductor field-effect transistor) scaling and miniaturization has been the primary factor behind the rapid exponential growth of semiconductor technology since the 1960s.

The semiconductor industry is an extensive and competitive industry. Competition is intense, with product innovation, fueled by aggressive research & development (R&D), paving the way for increased profitability, since consumers crave the newest offerings.

The industry is one of the more cyclical sectors in the Value Line universe and is characterized by strong long-term growth, with periodic cyclical downturns. During times of economic prosperity, the chip sector thrives, thanks to increased spending on the corporate and consumer sides.

However, during economic downturns revenues come under pressure, as corporate information technology budgets are pared and consumers hold off on purchasing the latest gadgets. The Semiconductor Industry is inherently more volatile than many other sectors. Members of the group constantly have to deal with the effects of the broader economic cycle, ever-shortening product lifecycles, and persistent peer competition.

Increasing revenues is important for semiconductor companies. This is because higher sales allows for improved fixed cost absorption. In addition, manufacturing is a major cost-control area for a semiconductor company. Implementing production improvement methodologies is a key means to lowering the breakeven point. Indeed, U.S. semiconductor industry labor productivity has more than doubled since 1999. These productivity gains have been made possible by maintaining high capital investment levels and R&D spending rates (Erik Pederson *et Al*, 2020).

"Over the past three decades the semiconductor industry has experienced rapid growth and delivered enormous economic impact. The semiconductor market grew at a 7.5% compound annual growth rate from 1990 to 2020, outpacing the 5% growth of global GDP during that time. Worldwide semiconductor sales increased from $149.4 billion in 1999 to $412.3 billion in 2019, a compound annual growth rate of increase of 5.21 percent per year. According to the World Semiconductor Trade Statistics (WSTS) Fall 2019 Semiconductor Industry Forecast, worldwide semiconductor industry sales are forecast to reach $433 billion in 2020 and $460 billion in 2021" (Erik Pederson *et Al*, 2021, Page 2).

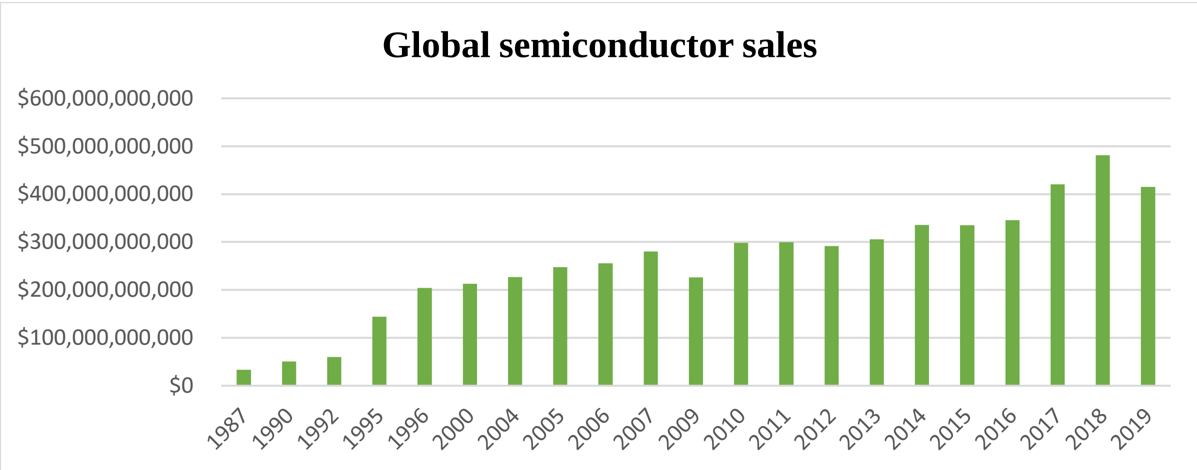

Figure 3.1 Illustration of the global semiconductor sales (Erik Pederson *et Al*, 2021).

3.1.1 R&D and Capital investment

Semiconductors are highly complex products to design and manufacture. No other industry has the same high level of investment in both R&D (22% of annual semiconductor sales to electronic device makers) and capital expenditure (26%) (Antonio Varas *et Al*, 2021, page 4).

As a result, the semiconductor industry presents both high R&D and high capital intensity. Overall, is estimated that in 2019 the industry invested about $90 billion in R&D and $110 billion in capital expenditure globally across all the activities in the value chain. These two figures combined represent almost 50% of the $419 billion in global semiconductor sales in the same year. Considering the investments made by firms across the entire global value chain, no other industry has the same high level of intensity in both R&D (22% of annual final chip revenues, ahead of pharmaceuticals) and capital expenditure (26% of final chip revenues, ahead of utilities). This extremely high level of investment intensity creates the need for large global scale and specialization (Antonio Varas *et Al*, 2021).

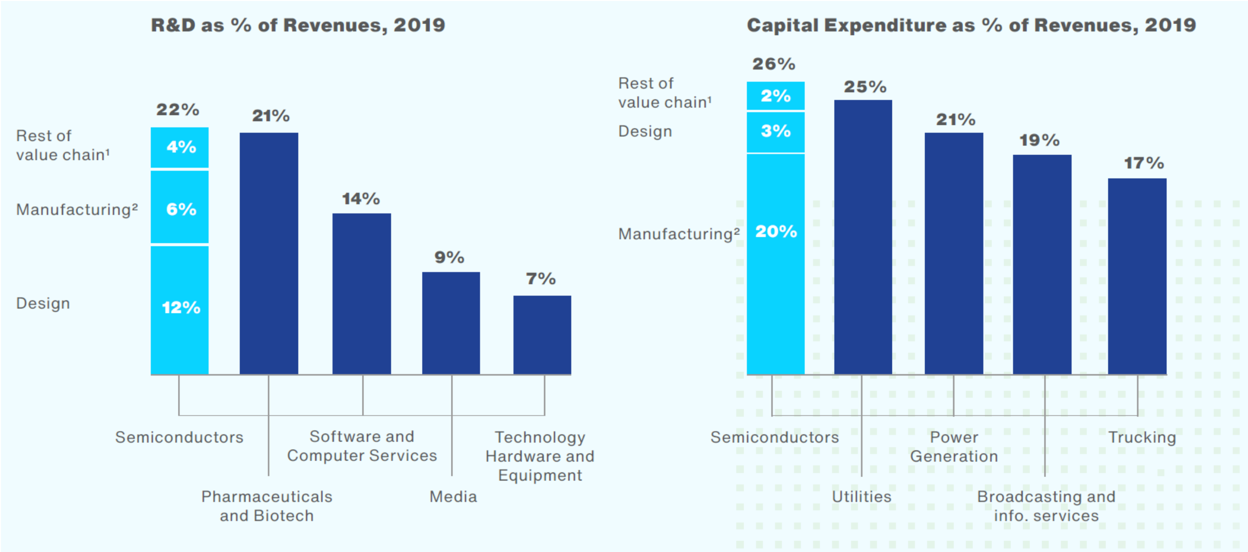

Figure 3.2 R&D and Capital expenditure as % of Semiconductor revenues (Antonio Varas *et Al*, 2021, page 22).

1.Includes EDA and Core IP, Equipment and Materials 2. Includes Wafer Fabrication and Assembly, Packaging & Testing.

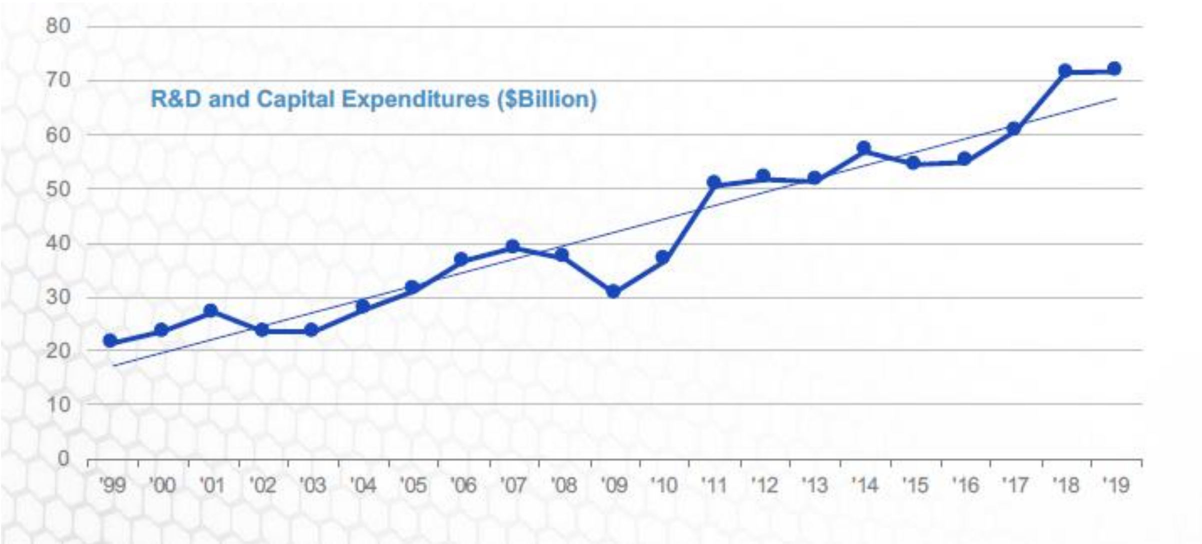

Figure 3.3 R&D and Capital expenditures by US semiconductor firms (Erik Pederson *et Al*, 2021, page 14).

In order to remain competitive in the semiconductor industry, firms must continually invest a significant share of revenues in both R&D and new plant and equipment. The pace of technological changes in the industry requires that companies develop more complex designs and process technology and introduce production machinery capable of manufacturing components with smaller feature sizes. The ability to design and produce state-of-the-art semiconductor components can only be maintained through a continual commitment to keeping pace with industrywide investment rates of roughly 30 percent of sales.

To understand the crucial role of the Semiconductor industry, we can look at two main data, about the U.S. semiconductor industry: U.S. exports of semiconductors were worth $46 billion in 2019, fifth highest among U.S. exports behind only airplanes, refined oil, crude oil, and autos. Semiconductors constituted the largest share of U.S. exports of all electronic product exports (Erik Pederson *et Al*, 2020).

3.1.2 Semiconductor industry structure

Data in 3.2 sub chapter, from (Antonio Varas *et Al*, 2021, page 14-21).

Semiconductor companies have three distinct engineering capabilities: core product design and engineering, design and technology enablement (or infrastructure engineering), and operational engineering (process and manufacturing engineers for yield, test, product and quality).

The industry value chain involved in the creation and production of any semiconductor is extraordinarily complex and globalized. At a high level, it consists of four broad steps:

1- *Pre-competitive research;*
2- *Chip design;*
3- *Front end (wafer fabrication);*
4- *Back end (assembly, packaging & testing);*

Supported by a specialized ecosystem of materials, equipment and software design tools and core IP suppliers:

1- *EDA & Core IP;*
2- *Equipment & tools;*
3- *Materials.*

The semiconductor value chain includes seven differentiated activities

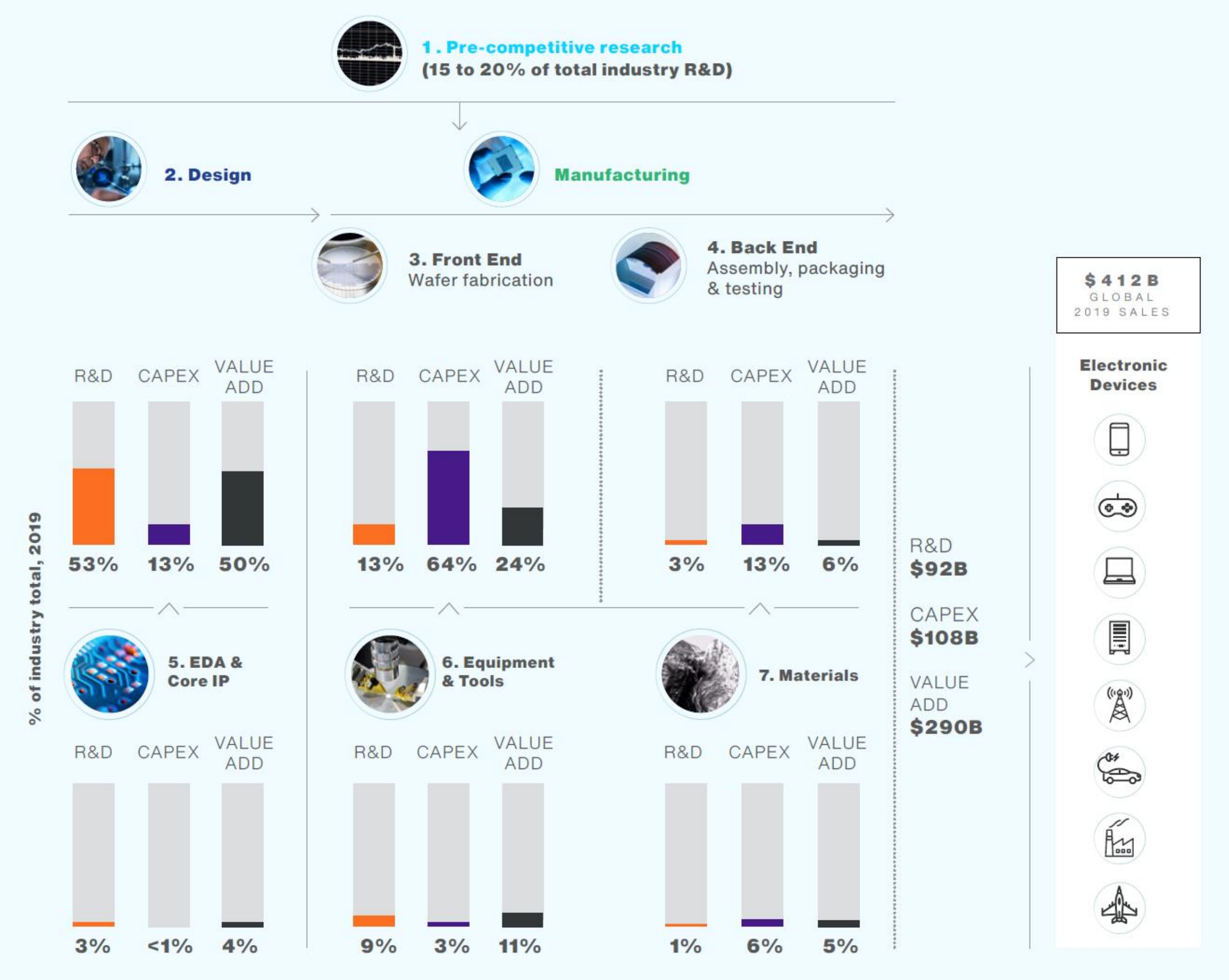

Figure 3.4 Semiconductor value chain (Antonio Varas *et Al*, 2021, page 13)

Pre-competitive research (15 to 20% of total industry R&D)

All starts form the pre-competitive research is aimed at identifying the fundamental materials and chemical processes to seed the innovations in design architectures and manufacturing technology that will enable the next commercial leaps in computing power and efficiency. It is typically basic research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community. In particular, governments have a very significant role in advancing basic research. The average length of time between when a new technological approach is introduced in a research paper and when it hits widescale commercial manufacturing is estimated to be about 10-15 years, but is a crucial activity to put a base, for the industry enhancement. For example, China is committing large sums to precompetitive research as part of its effort to build a strong domestic semiconductor industry.

Chip design (53% of industry R&D)

Design relies on highly advanced electronic design automation (EDA) software and reusable architectural building blocks ("IP cores"), and in some cases also outsourced chip design services provided by specialized technology suppliers. Design activity is largely knowledge- and skill-intensive: it accounts for 65% of the total industry R&D and 53% of the value added. Indeed, firms focusing on semiconductor design typically invest 12 to 20% of their annual revenues in R&D.

Electronic design automation & core IP

At the design stage, EDA companies provide sophisticated software and services to support designing semiconductors. With billions of transistors in a single chip, state-of-the-art EDA tools are indispensable to design competitive modern semiconductors.

Core IP suppliers license reusable components designs – commonly called "IP blocks" - with a defined interface and functionality to design firms to incorporate into their chip layouts.

EDA and core IP vendors invest heavily in R&D – about 30 to 40% of their revenues – and accounted for approximately 4% of the value added of the industry in 2019.

Wafer processing and testing equipment

Semiconductor manufacturing uses more than 50 different types of sophisticated wafer processing and testing equipment provided by specialist vendors for each step in the fabrication process. Semiconductor manufacturing equipment companies typically invest 10 to 15% of their revenues in R&D. Overall semiconductor equipment manufacturers suppliers accounted for 9% of the R&D and 11% of the value added of the industry in 2019.

Materials

Finally, firms involved in semiconductor manufacturing also rely on specialized suppliers of materials. Semiconductor manufacturing uses as many as 300 different inputs, many of which also require advanced technology to produce.

Production of these highly specialized materials is done in large plants, which also require high investments. Annual capital expenditure by the leading global suppliers of silicon wafers, photoresistors or gases typically ranges between 13 and 20% of their revenues. Overall, materials suppliers contributed 6% of the total capital expenditure and accounted for 5% of the value added of the industry in 2019.

WAFER FABRICATION

Highly specialized semiconductor manufacturing facilities, typically called “fabs”, print the nanometer-scale integrated circuits from the chip design into silicon wafers. Each wafer contains multiple chips of the same design. The actual number of chips per wafer depends on the size of the specific chip.

The average time to fabricate finished semiconductor wafers, known as the cycle time, is about 12 weeks.

Front-end manufacturing is highly capital intensive due to the scale and complex equipment needed to produce semiconductors. A state-of-the-art semiconductor fab of standard capacity requires roughly $5 billion (for advanced analog fabs) to $20 billion (for advanced logic and memory fabs) of capital expenditure, including land, building, and equipment. Capital expenditure of firms focusing on semiconductor manufacturing typically amounts to 30 to 40% of their annual revenues. As a result, wafer fabrication accounts for approximately 65% of the total industry capital expenditure and 25% of the value added. It is concentrated primarily in East Asia (Taiwan, South Korea and Japan) and mainland China.

ASSEMBLY, PACKAGING & TESTING

This stage involves converting the silicon wafers produced by the fabs into finished chips that are ready to be assembled into electronic devices. Firms involved at this stage first slice silicon wafers into individual chips. Chips are then packaged into protective frames and encased in a resin shell. Chips are further rigorously tested before being shipped to electronic device manufacturers.

The back-end stage of the supply chain still requires significant investments in specialized facilities.

Overall, this activity accounts for 13% of the total industry capital expenditure and contributed 6% of the total value added by the industry in 2019. It is concentrated primarily in Taiwan and mainland China, with new facilities also being built recently in Southeast Asia (Malaysia, Vietnam, and the Philippines).

3.1.3 Demand by region

Demand for semiconductors is highly global. The share of the global semiconductor demand that comes from each region is different depending on how the point of origin of demand is defined. While semiconductors are typically sourced by the electronic device makers to build their products, ultimately semiconductor demand is driven by the end users who purchase those devices. This is why, from a geographic standpoint, there are three different ways of measuring the origin of semiconductor demand, with reference to alternative points in the global electronics supply chain:

A- *Location of the headquarters of the electronic device makers:*
These firms are the customers of the chip companies, purchasing the semiconductors that go into their devices.

B- *Location where the device is manufactured/assembled:*
OEMs often do not manufacture their devices in the same country where their headquarters are located or where the engineering team that designed the device is based. This is the location where the finished semiconductors need to be physically shipped to.

C- *Location of the end users that purchase the electronic devices:*
Given that semiconductors are components, semiconductor demand is ultimately driven by sales of electronic devices to end users, both consumers and businesses.

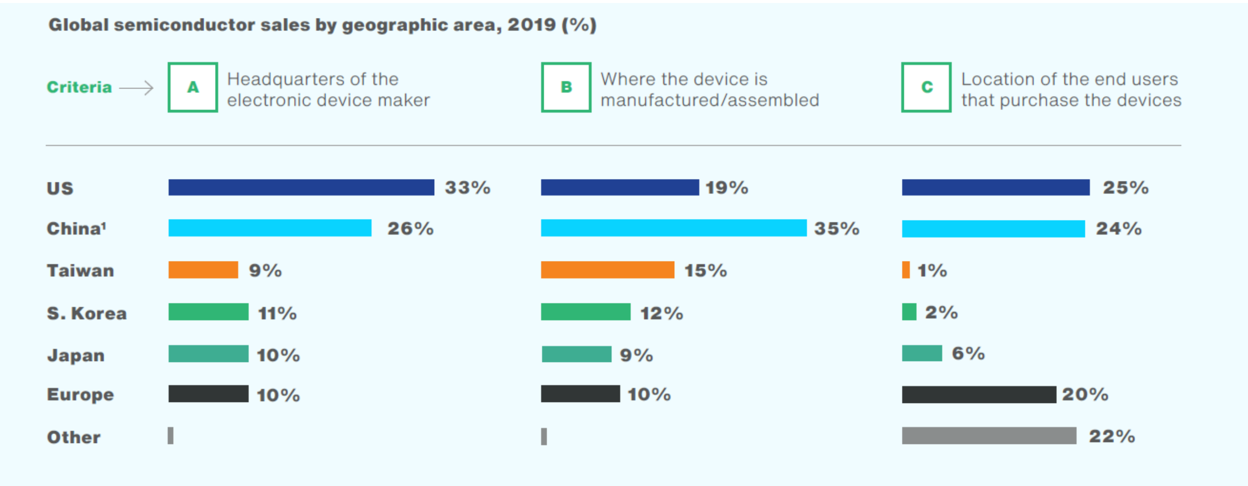

Figure 3.5 Global semiconductor sales by geographic area (Antonio Varas *et Al*, 2021, page 11)

The figure 3.5 above shows the geographic breakdown of the global semiconductor demand using the three alternative lenses.

Considering the location of the electronic device makers (criterion A in the exhibit 1.6), the US still drives 33% of the total global semiconductor demand, the highest participation across all regions. In general, US and China are the largest semiconductor markets, each accounting for

25% of global consumption. China is the top region under the end electronics device manufacturing/assembly location criteria (criterion B in the exhibit 1.6), reflecting its strength in electronics manufacturing, particularly smartphones and consumer electronics products. As the world's main manufacturing hub, China was the destination for approximately 35% of total global chips sales in 2019.

Focusing on where the devices are effectively sold to end users (criterion C in the exhibit 1.6) shows where semiconductor demand is ultimately coming from. As we can see, the main markets are U.S., EU and China.

In 2001, the Asia Pacific market surpassed all other regional markets in sales, as electronic equipment production shifted to the region. It has multiplied in size since then - from $39.8 billion to over $258 billion in 2019. By far, the largest country market within the Asia Pacific region is China, which accounted for 56 % of the Asia Pacific market and 35 % of the total global market. This data reflects sales of semiconductors to electronic equipment makers only – final electronic products containing semiconductors are then shipped for consumption around the world (Erik Pederson *et Al*, 2020).

Today U.S.-based firms have the largest market share with 47 percent. Other countries' industries have between 5 and 19 percent global market share. The U.S. semiconductor industry is a key driver of America's economic strength, global competitiveness, and technology leadership.

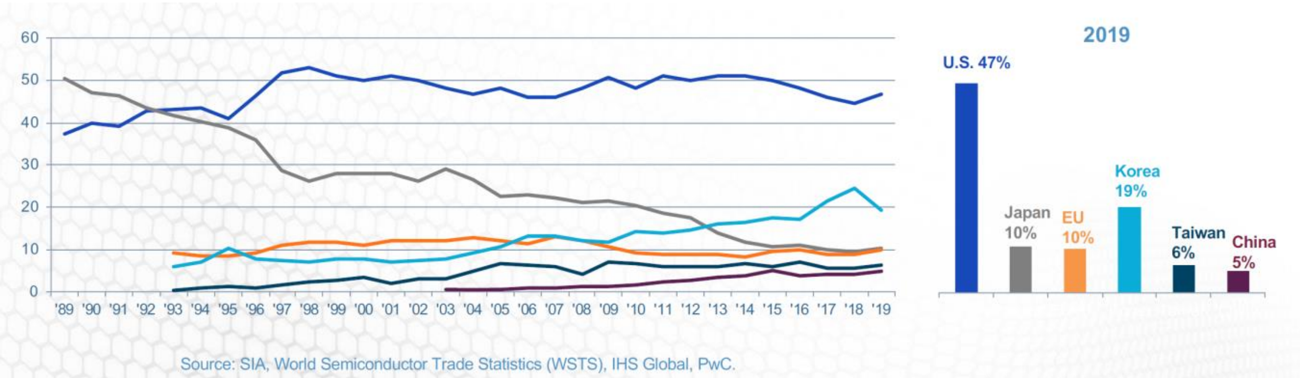

Figure 3.6: 2019 Global semiconductor market share (Erik Pederson *et Al*, 2020, page 3).

3.2 Examples of typical products

Semiconductors materials can be able to conduct electric current, can be easily regulated, and can act as both insulators and conductors. These qualities have made semiconductors useful in the electronics field since its inception. The conductivity of the semiconductor is generally sensitive to temperature, illumination, magnetic field, and minute amount of impurity atoms. This sensitivity in conductivity makes the semiconductor one of the most important materials for electronic applications.

A semiconductor material has an electrical conductivity value falling between that of a conductor, such as metallic copper, and an insulator, such as glass.

To practically use semiconductors their conductivity must be immensely increased. This is accomplished by adding a small amount of other atoms (impurities) to the semiconductor, so in the crystalline structure (extrinsic semiconductor). These impurities are referred to as dopants, and will increase conductivity by either adding electrons or holes to a semiconductor. Apart from doping, the conductivity of a semiconductor can be improved by increasing its temperature.

When two differently-doped regions exist in the same crystal, a semiconductor junction is created. The behavior of charge carriers, which include electrons, ions and electron holes, at these junctions is the basis of diodes, transistors and most modern electronics.

When a doped semiconductor contains free holes it is called "p-type"(semiconductor doped with acceptor impurities), and when it contains free electrons it is known as "n-type"(Semiconductors doped with donor impurities). Both types of extrinsic semiconductors are electrically neutral.

The materials chosen as suitable dopants depend on the atomic properties of both the dopant and the material to be doped. In general, dopants that produce the desired controlled changes are classified as either electron acceptors or donors.

The semiconductor materials used in electronic devices are doped under precise conditions to control the concentration and regions of p- and n-type dopants. A single semiconductor device crystal can have many p- and n-type regions; the p–n junctions between these regions are responsible for the useful electronic behavior.

Most commonly used semiconductor materials are crystalline inorganic solids, such as:

- *Silicon (S):* silicon is the most widely used type of semiconductor material. Its major advantage is that it is easy to fabricate and provides good general electrical and mechanical properties. Another advantage is that when it is used for integrated circuits it forms high quality silicon oxide that is used for insulation layers between different active elements of the IC (Integrated Circuit).

- *Gallium arsenide (GaAs):* Gallium arsenide is the second most widely used type of semiconductor after silicon. It is widely used in high performance RF devices where its high electron mobility is utilized.
- *Germanium (Ge)*: This type of semiconductor material was used in many early devices from radar detection diodes to the first transistors. Offers a better charge carrier mobility than silicon and is therefore used for some RF (Radio Frequency) devices. Not as widely used these days as better semiconductor materials are available.

(Hartmut Stadtler & Cristoph Kilger, 2004)

3.2.2 Production process

The production process of semiconductors consists of two stages each divided into two phases. The two stages are called front end and back end and are separated by a die bank. The front end consists of the wafer production and the wafer test phases whereas the back end is represented by the two phases assembly and chip test.

Front-end

- Wafer Production

  Starting point of every chip production is a round silicon disc. The so-called wafer does not represent a functional element of the future chip, but serves as the basis and carrier for the functional elements to be implemented (see Figure 1.9 below). Layers of conductive and isolating material are spread on the wafer in several repetitive processes. After each layer a photo chemical layer is spread on the top layer and exposed with a mask carrying the circuit information of each layer. This film is then developed to etch the circuits in an acid bath. Afterwards the photo chemical layer are removed and the next conductive or isolating layer can follow.

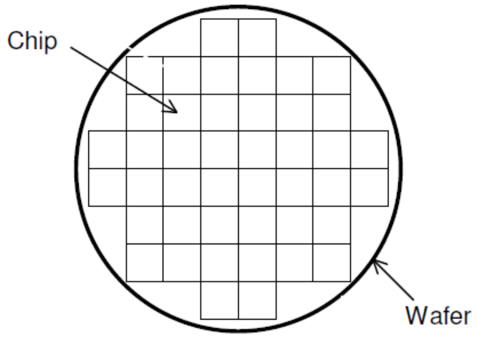

Figure 3.7: Wafer structure (Hartmut Stadtler & Cristoph Kilger, 2004, Page 423)

This process cycles six to twelve times per wafer depending on the complexity of the chip architecture. A number of several hundred small multilayer circuits and transistors can be developed on a single wafer. All wafers are processed in lots of typically 50 pieces. The maximum lot-size is defined by technical restrictions of the racks used to carry the material. The lot-size can also be less than 50 pieces if necessary to reduce the number of intermediate parts in the inventory, but it is tried to maintain the maximum lot-size over the whole process.

Chip manufacturing involves three basic operations: deposition, patterning and etching. Many processing steps are repeated many times in IC or chip fabrication, resulting in the buildup of microscopically thin layers of materials. In the process of building these layers, thousands or millions of transistors are created (transistor cycle) and interconnected (copper interconnected cycle).

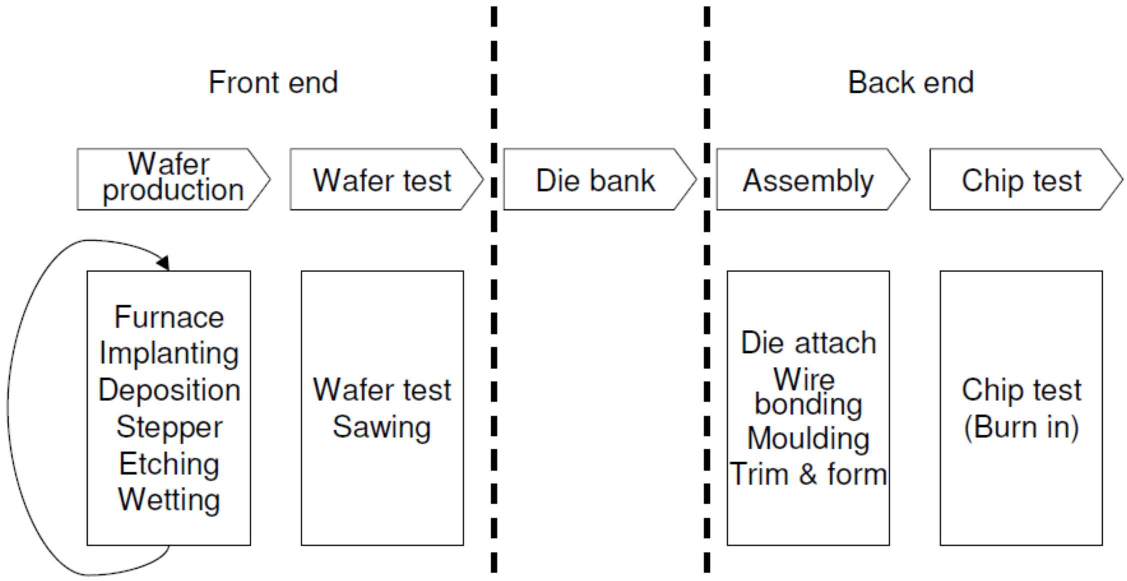

Figure 3.8: Semiconductor production process (Hartmut Stadtler & Cristoph Kilger, 2004, Page 424)

The wafers run through these repetitive process steps in four to six weeks. The constraint is a machine called ”stepper”, responsible for the positioning of the wafers and exposing the layers according to the mask. This process has to be conducted with great accuracy to avoid waste of material and capacity (represents a crucial bottleneck in the semiconductor production). Subsequently the intermediate product can be used to produce different finished goods. The production lead-time of this process is again four to six weeks. At the end of this process the wafers are ready to be shipped to the wafer test. When the process is completed a single wafer will contain hundreds of individual chips that are then cut from the wafer.

(Hartmut Stadtler & Cristoph Kilger, 2004)

- Wafer Test:
  The production process of the wafer test starts with the output of the preceding production step. This process is constrained by the availability of testing capacity. The testing capacity is usually a constraint to the complete semiconductor supply chain. After testing, the wafers are sawed to separate the single chips. The yield factor of the testing procedure depends on the quality of the production process and on the number of chips per wafer. Consecutively, the chips are shipped to the customer or stored in a finished goods stock.

Beck-end:

Usually the back end operates in a make-to-order mode.

- Assembly: in the assembly the chips are supplied from the central warehouse and are connected to the platforms, bonded and sealed in plastic.
- Chip-test: the production process is finished with the final quality control, where the finished element is aged artificially with high temperatures.

3.2.3 Electronic devices:

- *Diodes*: the simplest semiconductor device is the diode. It is a device that allows electric current to pass more easily in one direction than in the other. A diode consists of joined regions of p-type and n-type semiconductors.
  LEDs – Light Emitting Diodes: Diodes can do more than provide one-way paths for current. Diodes made from combinations of gallium and aluminum with arsenic and phosphorus emit light when they are forward-biased. When electrons reach the holes in the junction, they recombine and release the excess energy at the wavelengths of light.
- *Transistors:* a transistor is a simple device made of doped semiconducting material that is used in most electronic circuits. It usually consists of three terminals with one type of semiconductor sandwiched between two layers of the other type (n-p-n or p-n-p).

The central layer is called the base. The two surrounding regions are the emitter and the collector. Transistors act as miniature electronic switches. They are the building blocks of the microprocessor which is the brain of the computer.

MOSFET: The most widely used semiconductor device is the MOSFET (metal-oxide-semiconductor field-effect transistor, or MOS transistor), that is the key component upon which are made the majority of semiconductor applications. The MOSFET, which accounts for 99.9% of all transistors, is the driving force behind the semiconductor industry and the most widely manufactured device in history, with an estimated total of 13 sextillion (1.3 × 1022) MOSFETs having been manufactured between 1960 and 2018. Most of the essential elements of modern telecommunication are built from MOSFETs, including mobile devices, transceivers, base station modules, routers, RF power amplifiers, microprocessors, memory chips, and telecommunication circuits.

- *Integrated circuits (ICs):* is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material that is normally silicon. The integration of large numbers of many MOS transistors into a small chip results in circuits that are orders of magnitude smaller, faster, and less expensive than those constructed of discrete electronic components.

  Digital electronic circuits are usually made from large assemblies of logic gates, packaged in integrated circuits.

  The standard chips, are also known as commodity ICs, are simple chips used for performing repetitive processing routines. Produced in large batches, these chips are generally used in single-purpose appliances. By razor-thin margins, the commodity IC market is dominated by large Asian semiconductor makers.

- *Optoelectronic devices:* optoelectronics is based on the quantum mechanical effects of light on electronic materials, especially semiconductors.

  Main applications: LED and OLED (Organic Light Emitting Diode) applications.

- *Systems on a chip*(SoC): a system on a chip is an integrated circuit that integrates all or most components of a computer or other electronic system. The SoC, the newest type of chip, in the SoC, all of the electronic components needed for an entire system are built into a single chip. In a smartphone, the SoC might also integrate graphics, camera, and audio and video processing.

  SoC is essentially all about the creation of an integrated circuit chip with an entire system's capability on it. These components almost always include a central processing unit (CPU), memory, input/output ports and secondary storage, and a graphics processing unit (GPU), all on a single substrate or microchip.

They are also commonly used in embedded systems such as Wi-Fi routers and the IoT applications.

https://en.wikipedia.org/wiki/Semiconductor

Nodes

Advances in manufacturing process technology are typically described by referring to "nodes". The term "node" is meant to refer to the size in nanometers of the transistor gates in the electronic circuits, although over time it has lost its original meaning and has become an umbrella term to designate both smaller features and also different circuit architectures and manufacturing technologies.

Generally, the smaller the node size, the more powerful the chip, as more transistors can be placed on an area of the same size. This is the principle behind "Moore's Law", a key observation and projection in the semiconductor industry that states that the number of transistors on a logic chip doubles every 18 to 24 months. Moore's Law has underpinned the relentless pace of simultaneous improvement in performance and cost for processors since 1965. Today's advanced processors found in smartphones, computers, gaming consoles and data center servers are manufactured on 5 to 10-nanometer nodes. Commercial chip manufacturing using 3-nanometer process technology is expected to begin around 2023.

While logic and memory chips used for digital applications greatly benefit from the scaling in transistor size associated with smaller nodes, other types of semiconductors – particularly those in the DAO group described above—do not achieve the same degree of performance and cost benefits by migrating to ever smaller nodes, or simply use different types of circuits or architectures that would not work at more miniaturized scales. As a result, today wafer manufacturing still takes place across a wide range of nodes from the current "leading node" at 5 nanometers used for advanced logic to the legacy nodes above 180 nanometers used for discrete, optoelectronics, sensors, and analog semiconductors. In fact, only 2% of the global capacity is currently on nodes below 10 nanometers (Exhibit below).

Semiconductor firms compete on developing cutting edge technologies. Today, however, further advancing the technology has become more difficult as the physical limits of silicon transistors and circuits are being approached. How long Moore's Law is going to be applicable is unknown at present.

Today in 2020, Samsung and TSMC entered volume production of 5 nm chips and the development will keep shrinking the size of the chips.

(Antonio Varas *et Al*, 2021)

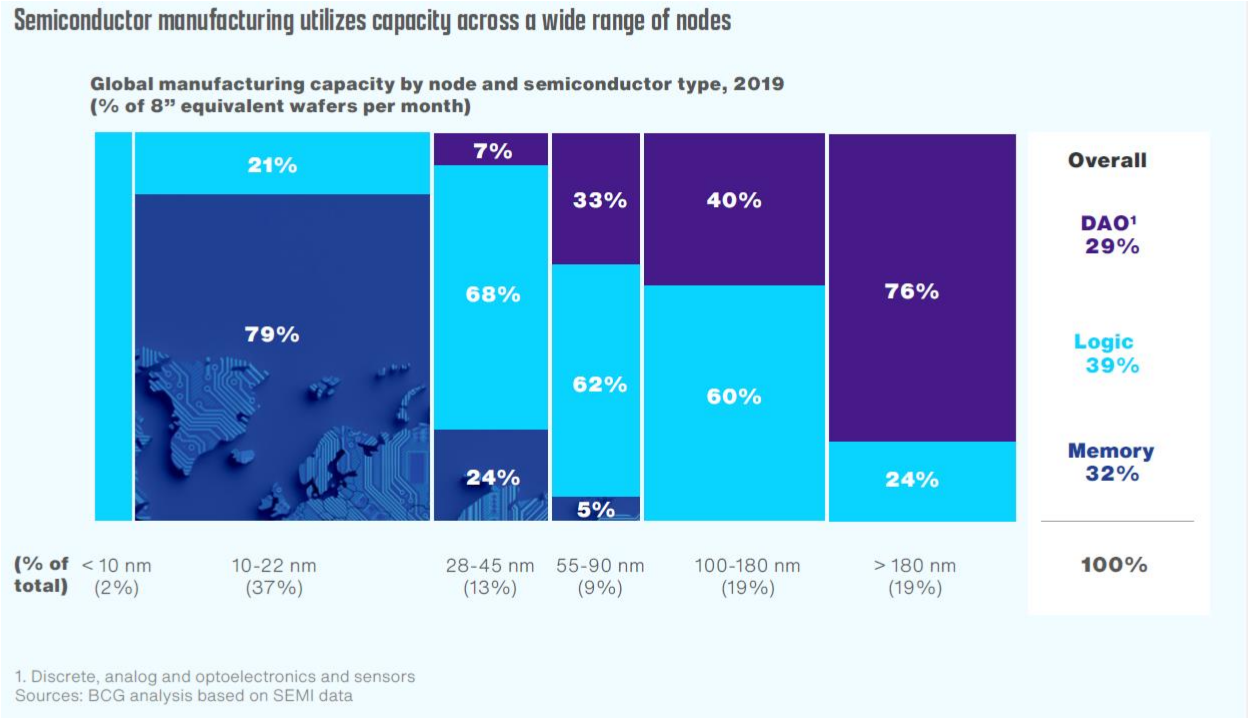

Figure 3.9: Semiconductor manufacturing utilizes capacity across a wide range of nodes (Antonio Varas *et Al*, 2021, page 18)

3.2.4 Semiconductor typology:

Semiconductors are highly specialized components that provide the essential functionality for electronic devices to process, store and transmit data. Most of today's semiconductors are integrated circuits, also referred to as "chips". A chip is a set of miniaturized electronic circuits composed of active discrete devices (transistors, diodes), passive devices (capacitors, resistors) and the interconnections between them, layered on a thin wafer of semiconductor material, typically silicon. Modern chips are tiny, packing billions of electronic components in an area as small as only a few square millimeters. While industry taxonomies typically describe more than 30 types of product categories, semiconductors can be classified into three broad categories:

1- ***Logic*** (42% of industry revenues):

These are integrated circuits functioning on binary codes (0 and 1) that serve as the fundamental building blocks or “brains” of computing:

Microprocessors are logic products such as central processing units (CPUs), graphics processing units (GPUs) and application processors (APs) that process fixed instructions stored on memory devices to execute complex computing operations. Applications include processors for mobile phones, personal computers, servers, AI systems, and supercomputers.

General purpose logic products such as Field Programmable Gate Arrays (FPGAs) do not contain any pre-fixed instructions, allowing a user to program custom logic operations.

Microcontrollers (MCUs) are small computers on a single chip. A microcontroller contains one or more processor cores along with memory and programmable input/output peripherals. MCUs perform basic computing tasks in myriads of electronic products such as cars, industrial automation equipment or consumer appliances.

Connectivity products, such as cellular modems, Wi-Fi or Bluetooth chips or Ethernet controllers, allow electronic devices to connect to a wireless or wired network to transmit or receive data.

2- ***Memory*** (26% of industry revenues)

These are semiconductors used for storing information necessary to perform any computation. Computers process information stored in their memory, which consists of various data storage or memory devices. Two most commonly used semiconductor memories in use today are Dynamic Random- Access Memory (DRAM) and NAND memory:

DRAM is used to store the data or program code needed by a computer processor to function. It is typically found in personal computers (PCs) and servers. Smartphones are also growing the DRAM content they require, and there is also increasing need for DRAM in automobile electronics applications such as advanced driver-assistance systems (ADAS).

NAND is the most common type of flash memory. Unlike DRAM, it does not need power to retain data, so it is used for permanent storage. Typical applications include solid state drives (SSDs) used as laptop hard drives or secure digital (SD) cards used in portable devices.

3- Discrete, Analog, and Other (DAO) (32% of the industry revenues)

These are semiconductors that transmit, receive, and transform information dealing with continuous parameters such as temperature and voltage:

Discrete products include diodes and transistors that are designed to perform a single electrical function.

Analog products include voltage regulators and data converters that translate analog signals from sources such as voice into digital signals. This category also includes power management integrated circuits found in any type of electronic device, and radio frequency (RF) semiconductors that enable smartphones to receive and process the radio signals coming from the base stations of cellular networks.

Other products include optoelectronics, such as optical sensors to sense light used in cameras, as well as a wide variety of non-optical sensors and actuators that can be found in all sorts of Internet of Things devices.

(https://www.investopedia.com/)

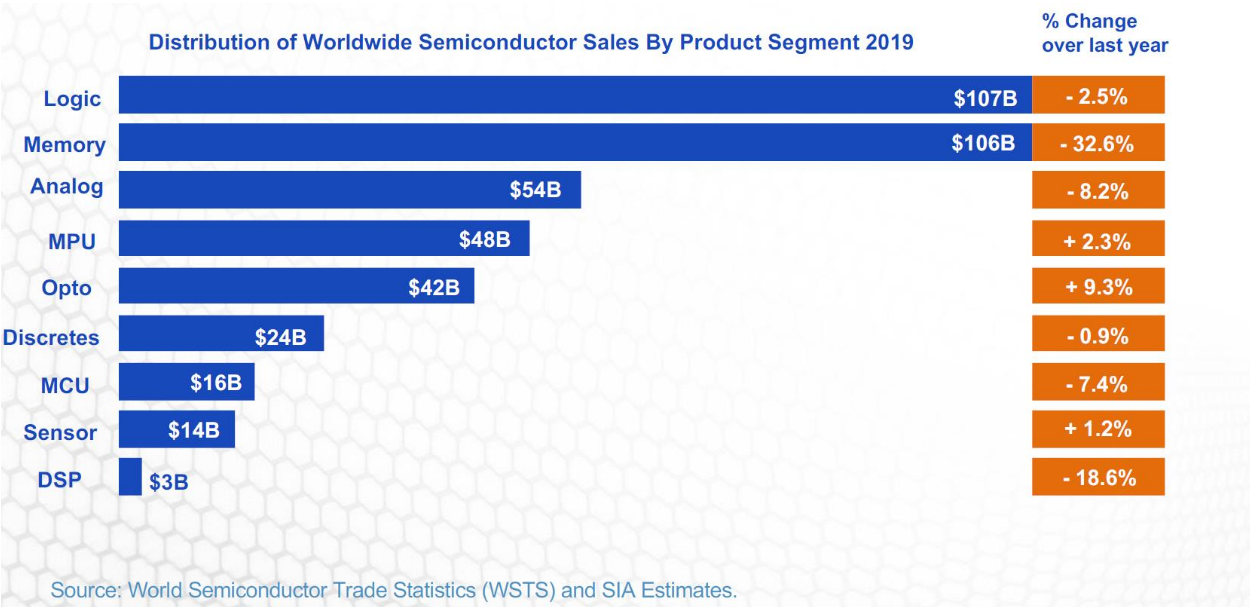

Figure 3.10 Distribution of Worldwide Semiconductor sales by product segment (Erik Pederson *et Al*, 2021, page 11)

Semiconductors are used in all types of electronic devices across multiple applications spanning the major sectors of the economy (Exhibit 1.13). Each of these application markets requires semiconductors from all three broad categories described above. For example, mobile phones have practically as much DAO content (essential for features such a cellular connectivity, camera and power consumption management) as logic content (which includes the microprocessors that provide increasing computing power with every new phone generation) and memory (for storage of digital content on the device). Approximately 65% of global semiconductor revenues are from general-purpose components that are used across multiple applications.

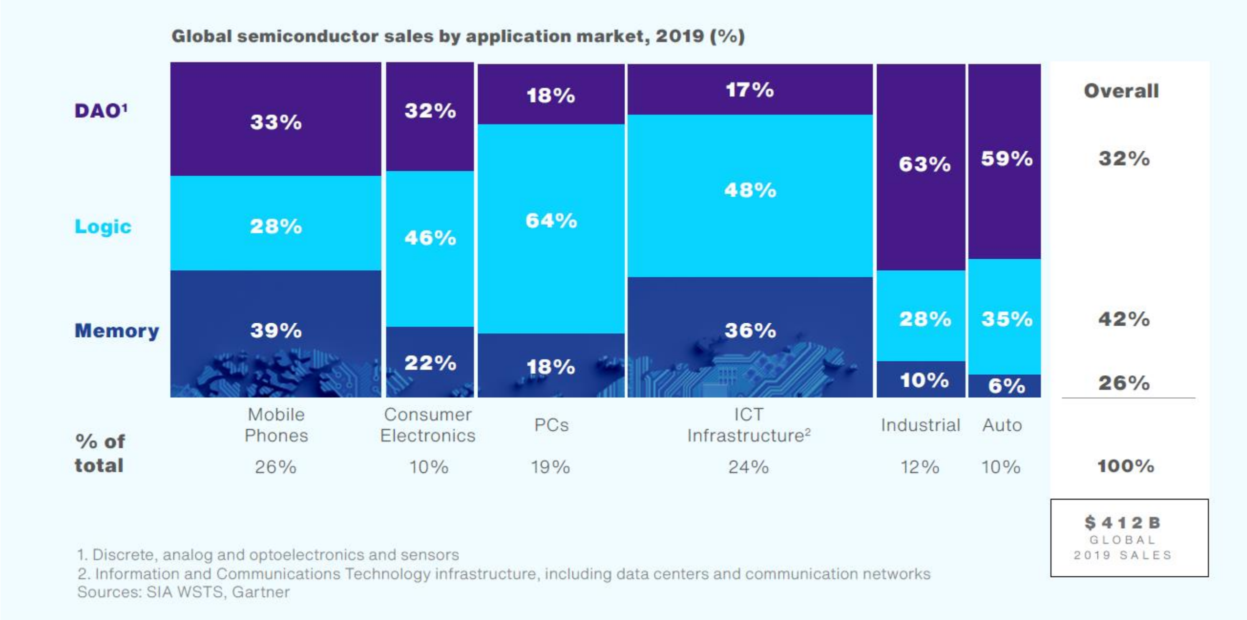

Figure 3.11: Global semiconductor sales by application market (Antonio Varas *et Al*, 2021, page 10)

All transistor types can be used as the building blocks of logic gates, which are fundamental in the design of digital circuits. In digital circuits like microprocessors, transistors act as on-off switches.

3.2.5 Semiconductor sales by product

Global semiconductor sales are driven by products ultimately purchased by consumers

The vast majority of semiconductor demand is driven by products ultimately purchased by consumers – be they laptops or communication devices such as smartphones. Increasingly, consumer demand is driven in emerging markets including those in Asia, Latin America, Eastern Europe and Africa.

The rise of mobile phones has been one of the semiconductor industry's main growth drivers over the past 15 years. A McKinsey report in 2012, showed as about 60 & of leading-edge- foundry output served the mobile segment, far outstripping microprocessors, graphics-processing units, and field programmable gate arrays.

Corporations and consumers globally use semiconductors in a millions of devices, semiconductor devices are omnipresent in a wide range of industries, including space vehicles, car computers, smartphones, medical equipment, appliances, and more.

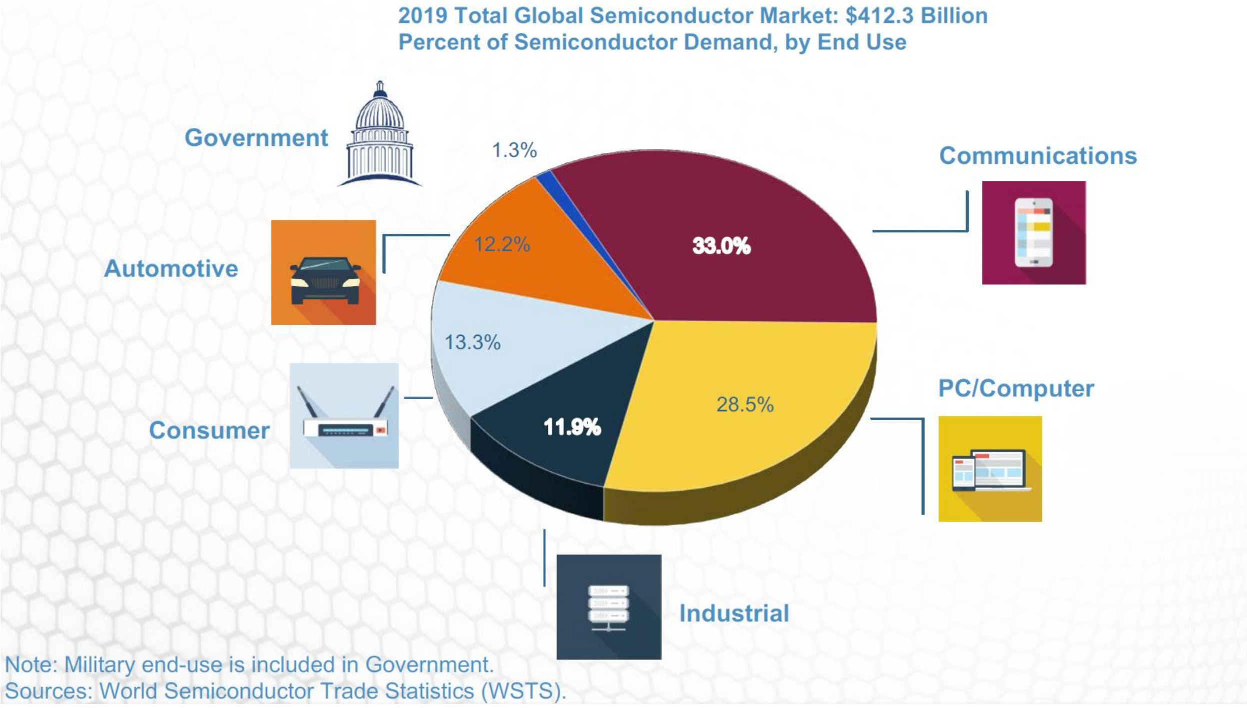

Figure 3.12 Global semiconductor market by end use (Erik Pederson *et Al*, 2021, page 10)

Key emerging semiconductor applications continue to grow end-use demand

AI, quantum computing, and advanced wireless networks are opening up new frontiers of semiconductor demand U.S. companies are poised to benefit from. If history is a guide, many applications that are unimaginable today will emerge in the future. When the first handheld cell phones – and later smartphones – appeared, people thought only executives would use them. Just over 40 years ago, the first four-function handheld calculators were sold in airline magazines for $500 each — an amount equivalent to almost $2,400 today. Then, handheld phones were receivers attached with wires to the actual phone on a desk or wall. Amazingly, calculator and phone functions are now virtually free in every smartphone sold, with the real value-add being the camera and internet connection. None of this could have occurred before there was first innovation in semiconductors (Erik Pederson *et Al*, 2021).

3.3. PESTEL analysis

Semiconductor companies must be aware of all external changes to advance and stay successful, from rapid advancement of the technology and all other factors. Indeed, in this industry, business performance is constantly under the influence of external factors. Continuous evolution of strategies is needed to support companies in this industry, especially when considering the rapid rate of innovation in the global market for products that involve microprocessors, such as laptops and smartphones and generally speaking the semiconductors environment.

3.3.1 Political factors:

Political factors, play a crucial role, mainly because can impact in the long term profitability of semiconductor companies. In the last 20 years, semiconductors have acquired a strategic role in the global politic system. Due to their applications in many strategic industries, semiconductor became a fundamental weapon for international equilibrium between countries. Indeed, in the last years, the main threat, coming from the political environment for the Semiconductor industry, is the trade war between US and China. In addition, the US has imposed restrictions on export of US-regulated products and technology to Chinese companies. Thus political misalignment and trade wars, have a significant impact on all the companies belonging to Semiconductor industry.

Trade liberalization

Semiconductors are the world's fourth most traded product. Being semiconductor industry a global market, there is the need to move materials, tools/equipment, products and IP across borders, which has been enabled by international trade agreements that eliminated tariffs and trade barriers for semiconductor products and reinforced the protection of intellectual property.

Integrated circuits are one of the products subject to the lowest tariffs in global trade. In particular, the World Trade Organization's Information Technology Agreement (ITA) effective since 1997 and further expanded in 2015, has been instrumental for the strong growth in international trade of semiconductor related products.

In 2019, global semiconductor trade reached $1.7 trillion in trade value. This is more than four times the value of 2019 global semiconductor sales, indicating the large magnitude of cross-border transactions involved in the development and manufacturing of semiconductors. In fact, semiconductors are the world's 4th most traded product. According to our analysis, more than 120 different countries (over 60% of the countries in the world) were involved as an exporter or importer of semiconductor products, signifying the scope and reach that the semiconductor industry has in the world (https://itif.org/)

Government intervention

The semiconductor industry has a longstanding tradition of partnering with government to spur innovation and build a bridge to the future. In the 1980s, the industry teamed with the US' government to establish SEMATECH, which sponsors advanced semiconductor manufacturing research and is now recognized by many as the ideal model of public-private collaboration.

Semiconductor products as logic chips (e.g. CPUs, GPUs and FPGAs) are especially critical for applications relevant to national and international security. Countries with serious economic and national security concerns may take a more focused approach, building some advanced semiconductor manufacturing capacity domestically in order to address their most sensitive needs in critical application areas.

In contrast, it is projected that during the next decade China will add about 40% of the new capacity and become the largest semiconductor manufacturing location in the world. As discussed earlier, the key factor behind this trend is economics: the total ten-year cost of ownership of a new fab located in the US is approximately 25- 50% higher than in Asia, and 40-70% of that difference is attributable directly to government incentives.

In semiconductor manufacturing economics, government incentives may account for up to 30-40% of the 10-year total cost of ownership (TCO) of a new state-of-the-art fab, which is estimated to amount to $10-15 billion for an advanced analog fab and $30-40 billion for advanced logic or memory.

The TCO of a new fab located in the US is approximately 25-50% higher than in Asia, and 40-70% of that difference is attributable directly to government incentives, which are currently much lower in the US than in alternative locations (Gaurav Batra *et Al*, 2018).

Manufacturing economics are significantly more favorable in Asia, with government incentives driving most of the cost advantage

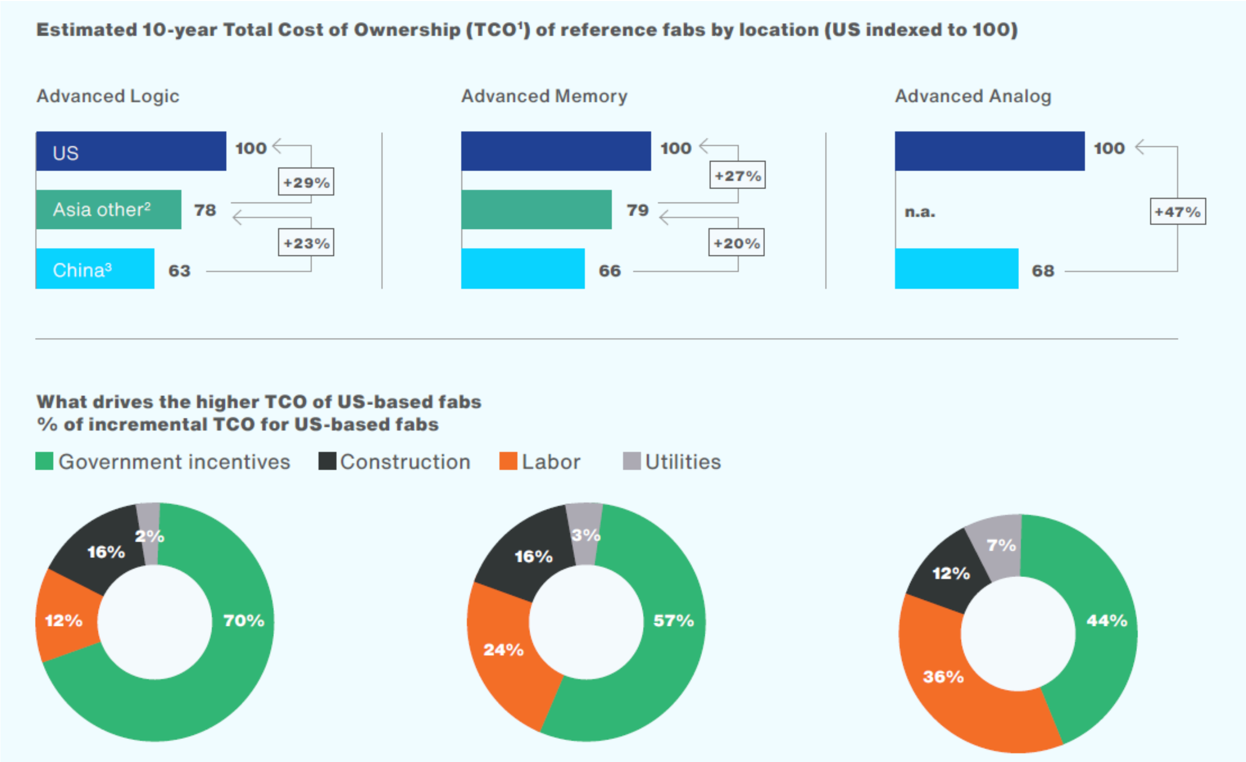

Figure 3.13 10-years total cost of ownership of fabs by location (Antonio Varas *et Al*, 2021, page 33).

1. TCO includes capital expenditure (upfront land, construction and equipment) + 10 years of operating expenses (labor, utilities, materials, taxes) 2. Refers to Taiwan and South Korea for logic, South Korea and Singapore for memory 3. With technology sharing agreements that give access to additional incentives such as equipment lease back with advantageous terms

Generally, government intervention relies on four main activities:

1- *Research*

Research investments in semiconductor-related fields such as materials science, computer science, engineering, and applied mathematics across federal scientific agencies to spur leap-ahead innovations in semiconductor technology that will drive key technologies of the future.

2- *Domestic Manufacturing*

Building new advanced manufacturing facilities, by providing tax incentives.

3- *Workforce*

Investing in high-skilled workforce.

4- Trade and IP

Approve and modernize free trade agreements, protect IP, and enable fair competition. Increase resources for law enforcement and intelligence agencies to prevent and prosecute semiconductor intellectual property theft, including the misappropriation of trade secrets.

<u>China</u>

A priority in the Chinese Communist Party's 14th Five-Year Plan (2021–25) is to strengthen China's autonomy in semiconductor production. This is in response to US sanctions restricting the supply of chips containing US technology to China.

<u>Taiwan</u>

Taiwan has been investing in the development of its domestic semiconductor manufacturing industry since 1974, when the government selected semiconductors as a key focus industry to expand the economy beyond agriculture. Policies pursued by the government included both direct support in the form of setting up R&D labs and industrial parks and providing incentives for the construction of new fabs such as generous tax-credits that could cover as much as 35% of their capital expenses and 13% of their equipment purchases, as well as indirect incentives such as reform of the financial sector and capital markets to facilitate access to funding. Is estimated that Taiwan still provides incentives for new fabs worth 25-30% of their overall total cost of ownership over a 10-year period. This is in line with other Asian locations such as South Korea and Singapore, but currently well below mainland China. In contrast, the incentives to new fab construction currently available in the US and Europe are estimated to reach just 10-15% of the total cost of ownership. Today Taiwan is home to 2 of the 5 largest foundries globally and hosts 20% of the total global capacity (https://www.bloomberg.com)

Geopolitical tensions that may impair global access to suppliers or customers

The geographic specialization of the semiconductor value chain can create some problems, when there are geopolitical tensions. They could also be subject to disruptions in scenarios of trade or geopolitical conflict that introduce restrictions to access to suppliers or technology originated in certain countries.

Overall, geopolitical tensions have been rising globally in the last 10 years. Ongoing geopolitical tensions in key semiconductor trade corridors in Asia and between the US and China present a rising risk to the industry supply chain.

3.3.2 Economic factors

Right now, the global pandemic glooms the economy and causes a high unemployment rate. TSMC's (the major foundry in the industry) customers might put off or downsize their new products forecast.

The fact that the Semiconductor Industry is going through an unbalanced demand as well as supply circumstance is not the only financial worry of the market. The excess supply in the industry is followed by a rate which is less than the expense of Semiconductor Industry which has caused capital problems for makers. Economic crisis is a major problem in the market because it can trigger low production. Improvements in efficiency degrees can cause enhanced production which results in economic downturn once again due to excess supply and also low need bring about closure of firms because of low earnings. There is a high possibility for economic crisis due to excess supply as well as low income of companies.

US

The U.S. semiconductor industry accounts for roughly a quarter of a million direct U.S. jobs and over a million additional indirect U.S. jobs. 241,134 direct jobs in the U.S. semiconductor industry, one U.S. semiconductor job supports 4.89 jobs in other parts of the U.S. economy, do that's more than 1 million additional American Jobs (Erik Pederson *et Al*, 2021).

The growth is attributed to the increasing consumption of consumer electronics devices across the globe. Additionally, the emergence of Artificial Intelligence (AI), Internet of Things (IoT) and machine learning is providing new opportunities to the market development.

(https://www.fortunebusinessinsights.com)

3.3.3 Social factors

Wages

The average manufacturing wages for skilled labor in mainland China, Taiwan and Southeast Asian countries such as Singapore and Malaysia are up to 80% below US levels. Today 9 of the 10 largest OSAT firms by revenue are headquartered in mainland China, Taiwan and Singapore. In terms of capacity location, mainland China and Taiwan account for more than 60% of the world's assembly, packaging and testing capacity. Recently OSAT firms have also started to diversify their own global footprint, building new capacity in other locations with low labor costs such as Malaysia. However, with the increasing level of technology innovation in the field of advanced packaging, labor cost may become less of a decisive factor going forward (Antonio Varas *et Al*, 2021).

TAIWAN

Social factors have actually likewise contributed towards the advancement of the Semiconductor Industry in Taiwan. The Taiwanese government has concentrated on human resources advancement in the market with trainings focused on enhancing the expertise of resources in the sector. The launch of the Semiconductor Institute in 2003 for training as well as developing talent is an instance of the social efforts to boost the industry. Although innovation was imported, getting sources familiar with the technology has been done by the government. Social initiatives to enhance the photo as well as high quality of the Taiwanese IC industry can be seen by the truth that it is the only industry which had properly developed departments of labor worldwide.

(https://casesteam.com/)

US

US government has empowered the next generation by allowing them to leverage their technical skills and experiences. Their purpose is to "inspire and empower young people around the world through technology, closing the global youth skills gap and ensuring that the next generation of innovators is empowered, more diverse and inclusive"(cit. Intel corporation).

U.S. Workforce: America's lead in semiconductors highly skilled workers having a competitive workforce. A key U.S. advantage has been the ability to attract talented people from all over the globe who come to study at American universities and choose to stay. Having access to a highly educated workforce, is critical to the future of America’s leadership in semiconductors.

(http://panmore.com/)

COVID-19: AUTOMOTIVE CASE

To better understand, how social factors impact the semiconductor industry, we can observe how the Covid-19 pandemic has changed the semiconductor demand.

Automakers across the globe are expected to lose billions of dollars in earnings this year due to a shortage of semiconductor chips. Semiconductor chips are extremely important components of new vehicles for areas like infotainment systems and more basic parts such as power steering and brakes.

Small changes in demand, due to social factors (as COVID-19), as they propagate further upstream in the value chain, the variability and the volatility grows dramatically.

The roots of the shortage lie in the early weeks of the pandemic, when auto plants worldwide abruptly shut down amid widespread stay-at-home orders.

Auto sales fell by almost half between February and April. As a result, car companies and their parts suppliers drastically cut their semiconductor purchases.
At the same time, demand for computers and other electronics soared as consumers tried to make their new work-from-home lifestyles palatable by bingeing on monitors, laptops and entertainment devices. So manufacturers of those items stepped up their chip purchases. The wafer and chip suppliers diverted the parts to other sectors such as consumer electronics, reallocating production.

Automotive chips yield lower profit margins than the newer, pricier semiconductors that power 5G smartphones and video games, which are also in high demand worldwide and dominate many manufacturing lines.

But demand for new vehicles was more resilient than expected during the shutdowns, particularly by consumers, so the industry recovered far quicker than anyone expected.

As automakers tried to place chip orders again, however, they found their suppliers busy making components for electronics companies.

In any cases, if you add 26 weeks (chips lead time) to when they made those decisions, the drop-off or the trough in the supply started to hit automotive the latter half of last year, going into Q1.

(https://www.cnbc.com)

3.3.4 Technological factors

The Semiconductor industry is expected to observe a year to year growth of 5.9% in 2020 compared to that of the previous year. This growth is governed by the new demand for new phones, 5G handsets require two to four times more power management chips than 4G phones do because of the complexity of the wireless technology.

New technologies

Technology is advancing in several ways, and research and development is putting out more useful products more quickly than ever before. Over the last 5 years the industry has been transforming really fast, not even giving chance to the established players to cope with the changes. A firm should not only do technological analysis of the industry but also the speed at which technology disrupts that industry.

So the demand grows following technological trends:

- High demand for data centric infrastructure, Increased requirement of fast storage and processing;
- Emerging fields of Artificial Intelligence;
- The transition of the network (5G network), the advent of 5G mobile connectivity has increased competition for chips;
- Edge and cloud computing;
- Internet of things, is a driving force to global digital transformation;
- Autonomous driving.

Research & Development

Being semiconductors highly complex products, need an high level of R&D investments. As forecasted by SIA (Semiconductor Industry Association), over the next ten years, the industry will need to invest about $3 trillion in R&D and capital expenditure globally across the value chain in order to meet the increasing demand for semiconductors, to understand the strategic role of R&D in the industry.

The US is the global leader in semiconductor R&D. It is home to some of the world's most prominent clusters of technical universities and semiconductor companies, which has resulted in a virtuous cycle of education, research, entrepreneurship, and access to capital to fuel innovation. While China has been investing aggressively in semiconductor R&D and currently files the largest total number of semiconductor academic research papers and patents annually, the US is still the source of the most relevant innovation in the industry: together with Europe, it has the highest conversion from patents filed into triadic patents – typically regarded as a marker of high-quality innovation with global commercial potential – in semiconductors, and the average number of citations per US semiconductor patent is between three and six times higher than for patents from any other country in the world.

3.3.5 Enviromental factors

This factor is about reviewing if any pollution takes place during the whole manufacture procedure. The environmental factor could be a potential public risk and could harm a company's reputation.

Below the main actions, put in place:

- Combating the increase in E-waste;
- Reducing operational impact on climate and energy;
- Increase in environmental concern over hazardous emissions, Attitudes toward and support for renewable energy;
- Waste management in Technology sector;
- Recycling;
- Laws regulating environment pollution.

According to industry critics, the semiconductor industry also adversely impacts the environment, causing groundwater and air pollution and generating toxic waste as a by-product of the semiconductor manufacturing process. So many companies, focus on being leader in environmental sustainability, to create a source of competitive advantage.

3.3.6 Legal factors

The intellectual properties are a determinant aspect in this sector, because the core advantage of many semiconductor companies rely on intellectual property on product designs. For example the patent litigation may bother a company for the long-term development and profitability.

1- Increased regulation over patents and trademarks rights;
2- Increased focus on rule of competition.

The legal environment of Semiconductor Industry has issues and also chances in the form of IP civil liberties as well as lawful agreements. A company has the legal protection to shield its copyright (IP), processing and innovation which can boost the reliance of others on it. The Semiconductor Industry additionally offers a high relevance to legal agreements.

Legislation and legal limits are important to keep in mind throughout navigating the industry. Much of the legislation now in place in the United States currently refers to tax reform. There could potentially be changes that impact the nature of the global business environment for the semiconductor industry. The better tax rates for corporation here in the United States will improve the competitiveness in this area due to lower costs for large corporations.

In number of countries, the legal framework and institutions are not robust enough to protect the intellectual property rights of an organization. A firm should carefully evaluate before entering such markets as it can lead to theft of organization's secret sauce thus the overall competitive edge.

The improving intergovernmental action against monopoly facilitates companies' growth based on the increasing number of firms. Nonetheless, companies can benefit from the opportunities linked to improved protection for its intellectual properties, as governments cooperate to develop appropriate legal protections.

Due to their strategic role, and being part of the IT industry, semiconductor companies are subjected to legal issues like: intellectual property rights, software licensing, copyrights, trademarks, the safety of users confidential information and IP protection.

3.3.7 PESTEL conclusion

The PESTEL analysis gave a diversified image of which factors that is most important in the semiconductor industry. The technological and economic showed to be driving forces in the industry. The legal factor is not one of the main driving forces but important just as well, of the main driving forces but important just as well, especially the litigations concerning IP.

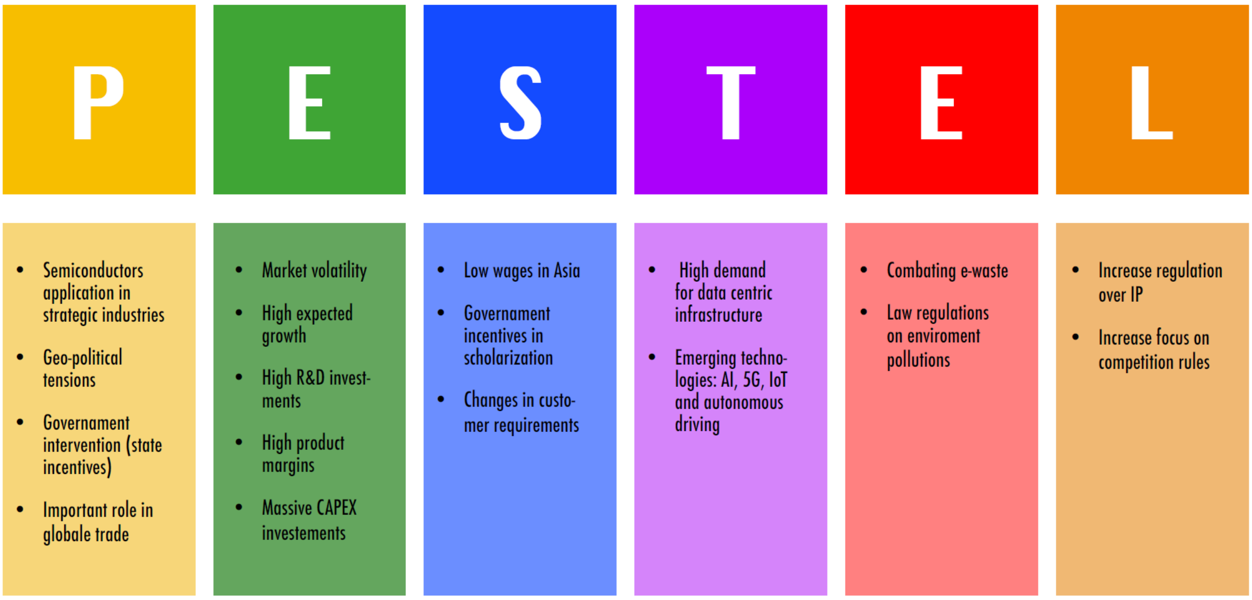

Figure 3.14 PESTEL analysis.

3.4 Semiconductor Main players

Semiconductors are hidden in phones, tablets, and computers. So many lesser-known business-to-business (B2B) companies are major suppliers of chips and other components. These suppliers, in turn, often sell these items to hardware companies that manufacture more recognizable, brand-name devices.

Semiconductor companies have three distinct engineering capabilities:

1- Core product design and engineering;
2- Design and technology enablement (or infrastructure engineering);
3- Operational engineering (process and manufacturing engineers for yield, test, product and quality).

Companies have long been structured to use these capabilities to deliver very specific semiconductor functionality for a small number of customers.

Chips are made in specialized factories called “fabs”, fabrication plants or simply foundries. Often referred to as the most sophisticated manufacturing plants in the world, mainly due to stringent cleanliness requirements.

The industry is based on the foundry model, which consists of semiconductor fabrication plants (foundries) and integrated circuit design operations, each belonging to separate companies or subsidiaries. Some companies, known as integrated device manufacturers, both design and manufacture semiconductors. Semiconductor companies generally organize their business activities around three main production processes: upstream, mid-stream and downstream. Companies that focus only on ICs design are commonly referred to as “fabless”, while companies that focus only on manufacturing are called “foundries”. Companies that are involved into both are called Integrated Device Manufacturers, or “IDMs”.

Ultimately, Semiconductor industry contains 3 main players and other complementary service providers:

1- “Pure-play” semiconductor foundry: pure play foundries only manufacture devices for other companies, without designing them.
2- Integrated circuit design operations (FABLESS): fabless manufacturing is the design and sale of hardware devices and semiconductor chips while outsourcing their fabrication to a specialized manufacturer called a semiconductor foundry;
3- Integrated device manufacturers (IDMs): is a semiconductor company which designs, manufactures, and sells integrated circuit (IC) products.
4- OSAT (Outsourced Semiconductor Assembly And Test): companies who perform IC packaging and testing. Vendors that provide third-party IC-packaging and test services.

IDMs and foundries with internal packaging operations also outsource a certain percentage of their IC-packaging production to the OSATs. The fabless companies also outsource their packaging to the OSATs and/or foundries.

The fabless and foundry models have a mutualistic relationship, whereas IDM competes with both the fabless and foundry models. IDM and the fabless–foundry model compete.

3.4.1 Pure-play semiconductor foundry:

Foundries
Segment economics
(% of annual revenue, 2016-2019)

▪ Gross Margin:	40%
▪ R&D:	9%
▪ Capex:	34%
▪ Operating Cash Flow:	15%

Foundries address the fabrication needs of fabless firms and IDMs alike, as most IDMs do not have sufficient installed manufacturing capacity in-house to cover all their needs. This business model

Figure 3.15 Foundries cost structure.

enables foundries to diversify the risk associated with the large upfront capital expenditure required to build modern fabs across a larger customer footprint of design firms and IDMs. Most foundries are focused purely on manufacturing for third parties, although some IDMs with strong manufacturing capabilities may also choose to make chips for others in addition to their own.

"Pure-player" semiconductor foundries are companies that do not offer IC products of its own design, but instead operates semiconductor fabrication plants focused on producing ICs for other companies.

Semiconductor foundries are companies that dedicate 100% of their business model to the manufacturing of chips for fabless IC semiconductor companies. Thus, foundries are not engaged in designing or marketing any of their own products and thus are viewed as a "neutral" manufacturing company which is not competing with their various product IC customers. To stay in business, foundries like TSMC and UMC in Taiwan, and SMIC in China, need to continuously keep investing on capital intensive semiconductor fabrication equipment and related facilities and support infrastructure resources. This investment is required to keep up with capacity requirements, technology node roadmap progression, wafer size changes, and new state-of-art fabrication equipment.

The component manufacturer creates the infrastructure and gets original equipment manufacturer to deliver custom solutions for the end product. Products based on amazing foundry technologies are developed in huge, sophisticated, very expensive foundry facilities. The majority of these products are then sold for a few cents or a few dollars each in mass markets.

The foundry is a microelectronics engineering and manufacturing business model consisting of a semiconductor fabrication plant, or foundry. Production facilities are expensive to build and maintain. Unless they can be kept at nearly full utilization, they will become a drain on the finances of the company that owns them. Indeed, foundries are typically, but not exclusively, located in China and Taiwan.

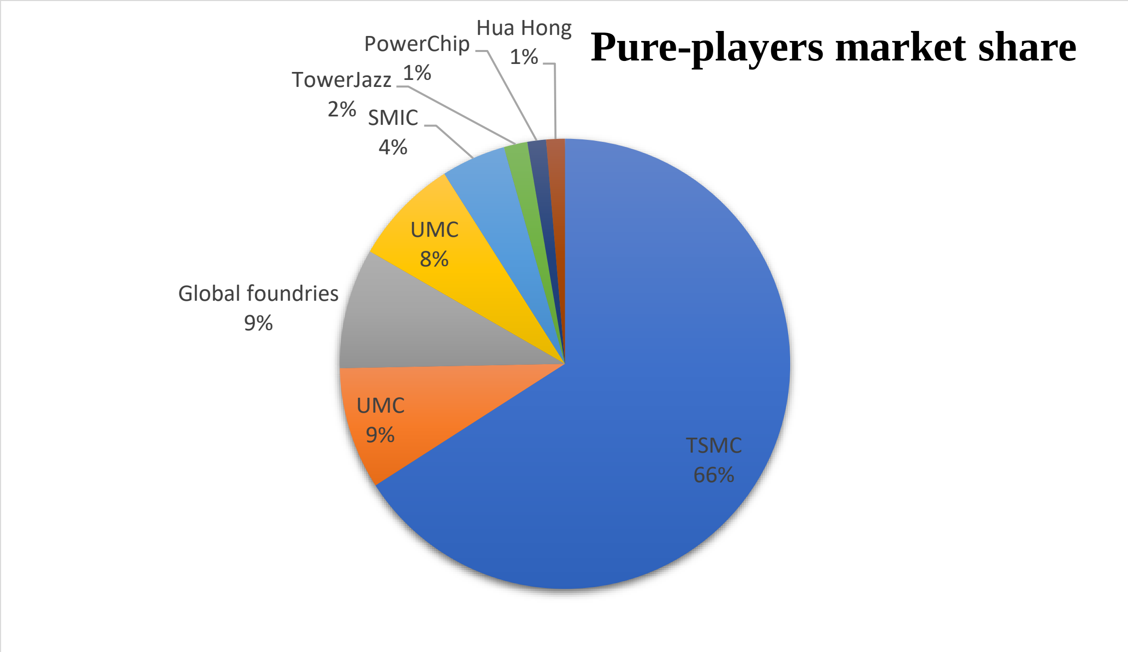

Figure 3.16 Pure players market share

https://www.eetasia.com

How we can see form the graph, the Taiwanese company TSMC has the substantial monopoly over the pure-play semiconductor foundry market.

Foundry's Cost structure: to build a new fab foundries have to justify the huge fixed initial investment. The required economics of scale in this industry are enormous. Both direct and indirect costs must be considered when owning and maintaining a fab.

- Direct fixed costs include: real estate, facilities, taxes, plant depreciation, equipment depreciation;
- Variable costs include: raw-wafer costs, consumables, labor (operators, process engineering support, equipment engineering and maintenance), equipment(maintenance costs and operating costs) and utilities.

These costs can add up for semiconductor companies that own fab facilities. Thanks to the birth of the Fabless-foundry model, plus other factors, many companies have allowed the pure-play foundries to incur the costs.

Today, the cost of developing a new factory that could hope to compete with an established player such as TSMC could cost upwards of $10 billion. When combined with the relatively low operational costs of the established foundries, this barrier to entry creates a significant incentive for fabless companies to continue outsourcing their manufacturing process.

Foundry revenue growth has consistently outpaced the growth of the semiconductor industry and is a good measure of the success of the fabless business model.

3.4.2 Fabless firm

Fabless
Segment economics
(% of annual revenue, 2016-2019)

• Gross Margin:	50%
• R&D:	20%
• Capex:	4%
• Operating Cash Flow:	20%

Figure 3.17 Fabless cost structure.

Fabless firms choose to focus on design and outsource fabrication as well as assembly, packaging, and testing. Fabless firms typically outsource fabrication to pure-play foundries and OSATs. The fabless model has grown along with the demand for semiconductors since the 1990s as the pace of innovation made it increasingly difficult for many firms to manage both the capital intensity of manufacturing and the high levels of R&D spending for design. As technical difficulty and upfront investment soared with the migration to smaller manufacturing nodes, total semiconductor sales accounted for by fabless firms increased from less than 10% in 2000 to almost 30% in 2019 (Antonio Varas *et Al*, 2021).

Fabless semiconductor companies do not have any semiconductor fabrication capability; and contract production from a merchant foundry manufacturer. The fabless company concentrates on the research and development of an IC-product.

Fabless semiconductor design companies do not own any manufacturing facilities and thus are totally focused in the design, marketing and sales of their products. Fabless companies are not "distracted" by the worries of intensive manufacturing capital investments and the associated internal resources required to keep the manufacturing facilities in operation. Fabless companies are at freedom to select any of the foundries that fit their needs in terms of technology, price, service or location. This selection freedom allows them to negotiate the best value to meet their needs and thus they are not "tied" down to a single supplier like in the case of IDMs.

Fabless companies can benefit from lower capital costs while concentrating their research and development resources on the end market.

Fabless companies are seeking to externalize other low added-value activities of the production process such as testing and packaging. Market leaders are therefore overall becoming leaner and asset-lighter, focusing on higher value-added operations such as R&D, supply-chain management and sales. A third type of companies, focused on intellectual property (e.g. ARM), exclusively specializes in designing semiconductors and licensing intellectual property to other chip manufacturing companies.

Vertically integrated players such as Intel and Samsung continue to invest in new process technologies to maintain their manufacturing leadership, focusing on increasingly smaller nodes.

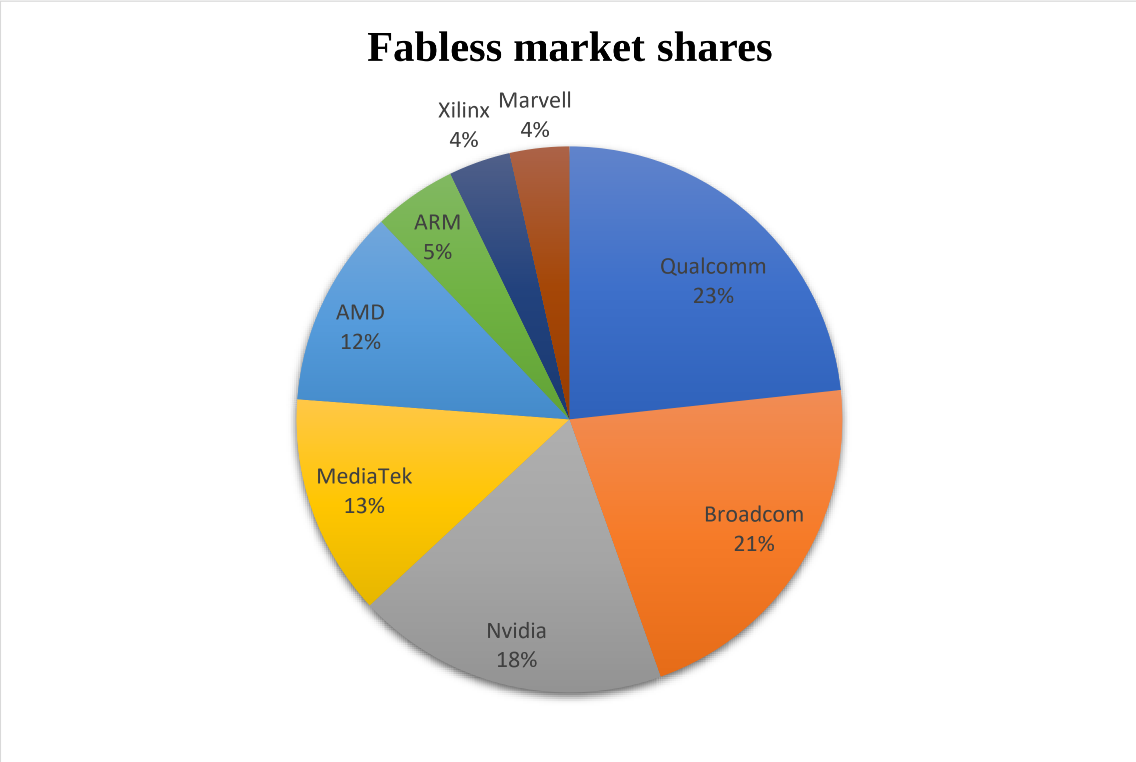

Figure 3.18 Fabless firms market share

(https://www.design-reuse.com)

As we can see from the chart above, almost the 65% of companies are headquartered in the U.S., since fabless companies need to invest a large amount of money, in order to sustain the unstoppable innovation trend of the sector.

3.4.3 Integrated device manufacturers

IDMs
Segment economics
(% of annual revenue, 2016-2019)

• Gross Margin:	52%
• R&D:	14%
• Capex:	20%
• Operating Cash Flow:	17%

Figure 3.19 IDM cost structure.

IDMs are vertically integrated across multiple parts of the value chain, performing design; fabrication; and assembly, packaging and test activities in-house. In practice, some IDMs have hybrid "fab-lite" models where they outsource some of their production and assembly.

In the early decades of the industry, the IDM model was predominant, but the rapidly increasing size of the investments in both R&D and capital expenditure created the simultaneous need for both scale and specialization, which led to the emergence of the fabless-foundry model.

IDMs accounted for approximately 70% of the global semiconductor sales in 2019 (Antonio Varas et Al, 2021).

A semiconductor company that designs, manufactures, and sells integrated circuits (ICs) is an integrated device manufacturer (IDM). A traditional IDM owns its own branded chips and does the design in-house and has a fabrication plant where it manufactures its ICs.

The IDMs have total ownership and control of all the required resources for semiconductor manufacturing: design automation tools, process libraries, process technology, fabrication and assembly equipment, test equipment, and all the necessary facilities and infrastructure resources.

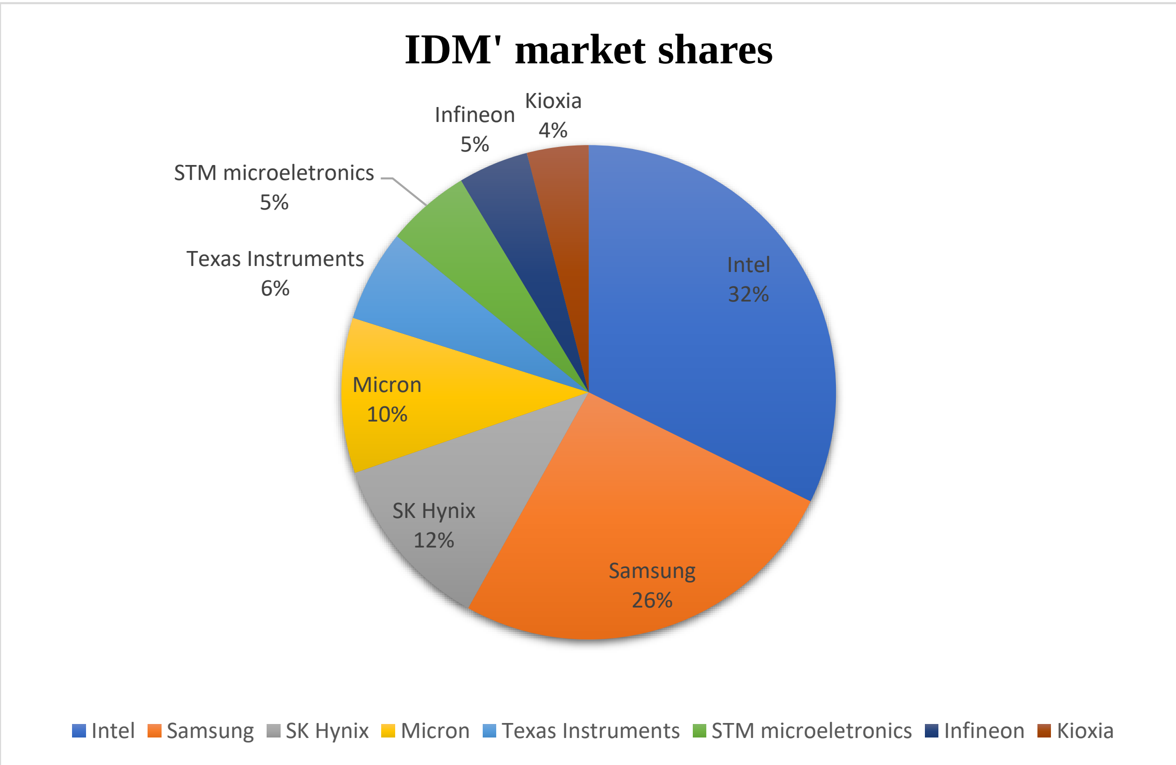

Figure 3.20 IDM's market shares

(https://en.wikipedia.org/)

3.4.4 Hybrids solutions

These are typically IDMs who outsource some of their manufacturing requirements to foundries when they need some additional capacity or some other processes not available in-house. This strategy allows the IDMs to bypass or delay additional capital expenditures.

Hybrid manufacturing strategies are primarily used by IDMs for many reasons:

- Complement their internal capacity constraints in times of up demand cycles, thus avoiding or delaying additional capital expenditures;
- As strategy for benchmarking their internal operations and cost performance against the foundries;
- To gain access to manufacturing technologies not yet developed in house;
- To get additional revenues off of their excess capacity in down demand cycles while still retaining their IDM model;
- To differentiate themselves with their own innovative semiconductor fabrication or packaging process. However, the real differentiator is in the integrated circuit (IC) design itself, not the manufacturing.

Even the IDMs at the top of the chip market rankings are gradually relinquishing control of manufacturing. Foundry process technology can be bought instead of being internally developed. In the last 20 years, due to the huge economics of scale required to justify capital investment in building a new fab, IDMs are gradually reducing their investment in fab.

3.4.5 Outsourced Semiconductor Assembly And Test

OSATs
Segment economics
(% of annual revenue, 2016-2019)

Gross Margin:	17%
R&D:	4%
Capex:	16%
Operating Cash Flow:	2%

OSATs provide assembly, packaging and test services under contract to both IDMs and fabless companies. This part of the supply chain was first offshored by some US IDMs starting back in the

Figure 3.21 OSAT cost structure.

1960s because of its lower capital intensity and the need for lower-skilled labor. The fabless-foundry model then also led to the emergence of specialized OSAT companies.

The global semiconductor industry market shares:

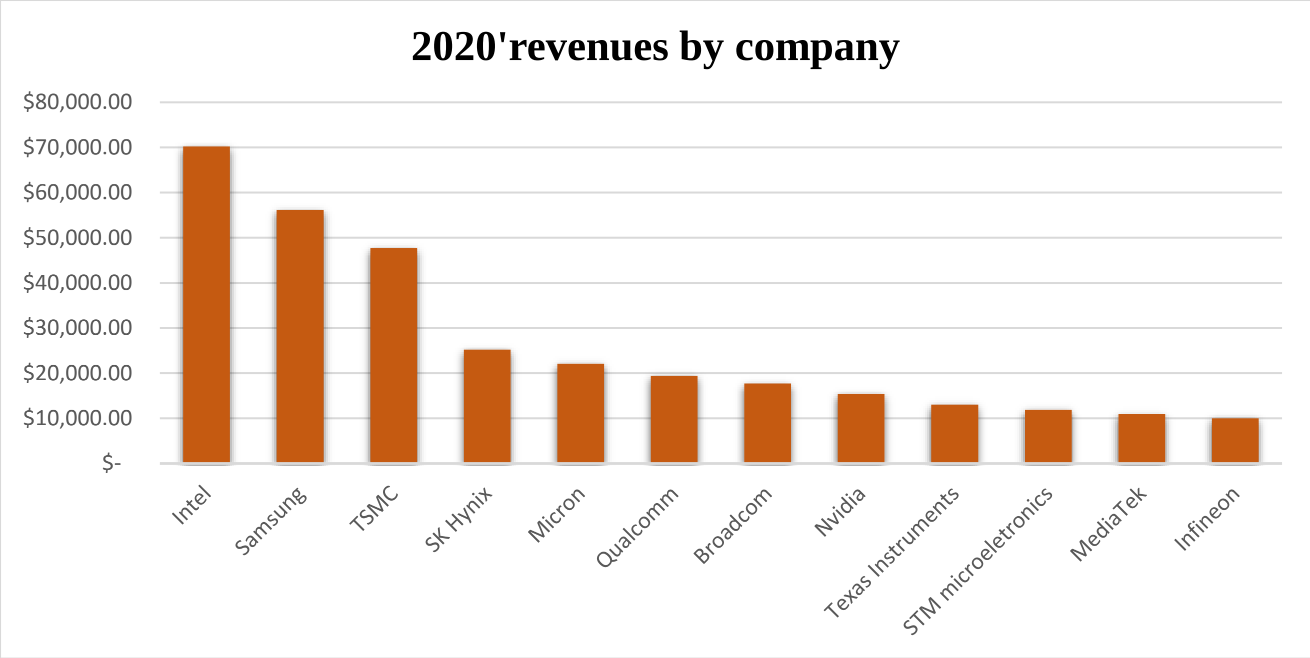

Figure 3.22 Global semiconductor market shares

(https://en.wikipedia.org/)

4 SEMICONDUCTOR BUSINESS MODELS

Today semiconductor companies may focus on one layer of the supply chain or integrate vertically across several layers. No company or even entire nation is vertically integrated across all. There are four types of semiconductor companies, depending on their level of integration and business model:

1- *The integrated device manufacturer (IDM):* IDMs have their own semiconductor manufacturing plants and resources and thus have direct control over their capacity, processes and resources;
2- *Fabless design firms:* these companies outsource all semiconductor manufacturing to foundries;
3- *Foundries*: foundry companies are concerned only with IC manufacturing.
4- *Outsourced assembly and test companies (OSATs).*

In this analysis, semiconductor industry is defined as "companies, which design and/or manufacture the chip", therefore it includes IDM, foundry and fabless companies. The business model resulting when fabless and foundry companies form a strategic alliance is called the fabless–foundry model. So in this analysis, are considered the main two business models in semiconductor industry:

- IDM business model;
- Fabless-foundry business model.

Recently, the revenue growth rate of the fabless–foundry model has been considerably higher than that of IDM. This raises the question of whether the fabless–foundry model will ultimately dominate the semiconductor industry or grow only to a certain extent. The ultimate market share of IDM is predicted to be approximately 55% and that of the fabless-foundry model approximately 45% (Hui-Chih Hung *et Al*, 2017).

Semiconductor value chain is the integration of technologies required to produce a chip or IC (integrated circuit).

In addition to the semiconductor product companies, the foundries make their business model that of performing 100% semiconductor manufacturing services for all above product companies. As such, foundries do not design or market products under their brand name, and thus are not viewed as competitors by their customers.

Business model evolution

In the early days of semiconductor industry, when IC complexity was low and IC design, fabrication and test processes were forming, the IDM business model worked well.

Indeed before 1990's, semiconductor industry is dominated by IDMs, which not only design and manufacture its own chips, but also design its own EDA tools. Due to scale economy, boom-bust cycle and productivity gain realized from Moore's Law semiconductor industry itself has been experiencing a major change in industry structure. This change was mainly because of the emergence of pure-players semiconductor foundry and fabless firms.

In a mature semiconductor industry where the product complexity is high, it is impractical and cost prohibitive for one company to handle all the processes. An ecosystem environment, where design and manufacturing tasks are handled in different locations by separate companies, means each ecosystem member can focus on its expertise. Intellectual property (IP) designers, fabless chip design houses or fabless semiconductor companies that own the chip brand, and pure-play foundries who make the chips, along with OSATs who package and test are all players in an ecosystem environment. An ecosystem brings some inefficiencies with it, but the overall gains are higher.

The industry shifted away from vertically integrated manufacturing toward a focus on core competencies. Companies began subcontracting activities they deemed lower in value, including a new emphasis on wafer manufacturing. Essentially, semiconductor companies, started to shift investments to areas that offered a competitive advantage. This trend challenged the long-held belief in market power gained through vertical integration. So, the uncoupling of semiconductor design and manufacturing became not only viable but also preferred for most semiconductor areas.

At the beginning, around the 90s, the semiconductor industry is one of the most technology-intensive industries, the silicon manufacturing process is cost prohibitive. So fabless companies relied on using excess capacity from IDMs to manufacture the chips they were designing at the beginning, and this is the birth of the fabless business model. But, before late 1980s fabless firms lived under the shadow of IDMs. In addition, at that time fabless depended on IDM for the manufacturing capacity, since fabless can't afford to build its own fab. To fabless firms, IDM is the worst supplier and competitor.

Thanks to the Taiwan government, the foundry industry was established with the founding of TSMC, becoming the cornerstone of the fabless model, providing a non-competitive manufacturing partner for these innovative fabless companies. Positioned as noncompetitive business partners, fabless and foundry companies have formed a strategic alliance that is termed the fabless–foundry model. In the late 1980s and 1990s Taiwanese firms pioneered the foundry model, specializing in manufacturing the chips designed by firms from other regions.

The value chain moved toward to horizontal and specialization. At that time organizations with low volume manufacturing needs, started to collaborate with foundries, that were willing to provide consistent solutions for these small companies and were committed to help fabless companies reach maturity. So, as the entry barriers reduced, the number of fabless firms increased a lot, specializing in emerging product segments.

Policies pursued by the government of Taiwan included both direct support in the form of setting up R&D labs and industrial parks and providing incentives for the construction of new fabs such as generous tax-credits that could cover as much as 35% of their capital expenses and 13% of their equipment purchases, as well as indirect incentives such as reform of the financial sector and capital markets to facilitate access to funding (Antonio Varas *et Al*, 2021). The model has been validated by the conversion of major IDMs to a completely fabless model. Many IDMs have flirted with the model over the years, and today most major IDMs including Infineon, Texas Instruments and others, have adopted outsourcing as major manufacturing strategy.

Furthermore, the mobile revolution gave a lift to global semiconductor sales, partially enabled by the fabless-foundry model, which allowed designers and manufacturers to bring powerful and innovative mobile chips to market rapidly.

4.1 Fabless-foundry business model:

The fabless-foundry model is a microelectronics engineering and manufacturing business model consisting of a semiconductor fabrication plant, or foundry, and an integrated circuit design operation, each belonging to separate companies or subsidiaries.

All foundries struggle with cost-effective manufacturing at the edge of what is physically possible. The massive complexity of modern semiconductors makes it a constant challenge to keep cost, quality and manufacturing cycle times in line.

The fabless-foundry business model has become the preferred model for semiconductor product companies, the foundries are not only keeping pace with the manufacturing capacity, pricing and service needs of their fabless customers, but also have started to lead in adopting the next process technology node at par with their IDM competitors.

Extremely high costs of integrated circuit manufacturing led to the separation of design and manufacturing giving rise to dedicated semiconductor foundry companies and dedicated semiconductor design companies without fabrication facilities, called "fabless" design houses. The fabless-foundry model is a business vision that seeks to optimize productivity.

Thanks to the fabless-foundry model, fabless companies can focus on their core activities: it must be more complicated than simply delivering the best designs. Successful fabless companies, own a set of key activities:

- *Essential market and customer understanding*

The biggest challenge is truly understanding customer needs and market problems and then defining the right products to fill those needs. The smaller the size of the chips, the greater the costs involved for their production, so understanding the needs and responding correctly becomes even more critical as the probable return for a given investment must be even greater than in prior product generations. So, successful companies clearly target large markets where they can be the number-one or -two player and earn required returns.

Many systems markets that consume semiconductor have consolidated and have become more concentrated with few large players. Thus, understanding market requirements often equals understanding the system needs of major players in their respective markets. This concept must be translated into revenues by engaging and winning market leaders early in the design cycle. These design wins need to be in markets that have enough growth and longevity to generate sustained revenue and returns. In addition, being the primary source on a reference design can increase revenue potential greatly for platforms that have become widely adopted by market-leading original equipment manufacturers.

- *Relentless focus in execution*

Fabless companies cannot succeed without execution. Tools and technologies are keys to enabling a team of well-managed, talented engineers to execute successfully. The continued advance of electronic design automation (EDA) tools and libraries enables fabless companies to well execute the today’s complex designs.

- *Relentless focus on Costs*

In addition to the fact that the fabless model enables a huge fixed-cost burden to be shifted to the foundry partner, fabless companies should focus on additionally driving down costs, and this is influenced by many factors. It is important to work closely with their foundry partner to use a process technology that optimally balances die cost, performance and technology risk when design ramps to production.

On the other hand, dedicated foundry offers several key advantages to fabless companies:

1- It does not sell finished IC-products into the supply channel, so a dedicated foundry will never compete directly with its fabless customers (obviating a common concern of fabless companies);
2- The dedicated foundry can scale production capacity to a customer's needs, offering low-quantity shuttle services in addition to full-scale production lines. Semiconductor foundry provides cost-effective IC manufacturing technology and wafer fabrication services to fabless IC design companies;
3- Finally, the dedicated foundry offers a "COT-flow" (customer owned tooling) based on industry-standard EDA systems, whereas many IDM merchants required its customers to use proprietary (non-portable) development tools. The COT advantage gave the customer complete control over the design process, from concept to final design.

This dedicated foundry or “foundry business model” established dedicated semiconductor foundries offering “pure-play” manufacturing only solution to fabless design houses. The foundry business model transformed the semiconductor industry facilitating easy market entry for design houses with innovative and niche product ideas.

The born of pure-players foundry enabled fabless firms to compete with IDMs. A fabless company faces the fixed cost in developing a chip design, that presents the single biggest initial investment. Without the need to invest in manufacturing equipment (foundry’s responsibility), the only thing fabless need to do is to concentrate on their value add, designing and marketing killer chip.

The foundry model uses two methods to avoid these costs:

1- Fabless companies avoid costs by not owning such facilities;

2- Merchant foundries, on the other hand, find work from the worldwide pool of fabless companies, and by careful scheduling, pricing, and contracting keep their plants at full utilization.

Fabless and foundry have the strong tie and interest to see each other prosper.

With the emergence of foundry business model, the separation of chip design and manufacturing functions becomes feasible. Fabless firms no longer have to rely on IDMs for manufacturing capacity.

The rise of the foundry model was further reinforced by two reasons:

1- The emergence of new semiconductor applications;

2- Rapidly changing technology introduced risks make IDMs reluctant to step in the new market during the early stages. Since new applications tend not to have dominant design, the total addressable market size is small at the beginning and cannot justify IDM's high capital investment in the fab, therefore IDMs are used to wait until the market grow big enough. So, by the time, market becomes viable, IDM missed the market window due to the long product development cycle.

   Indeed, Logic chips are fundamentally the realm of fabless firms. This dynamic is due to the pace at which the market demands improved power and performance capabilities in order to support the quick cycles of smartphones and emerging leading-edge applications in AI and high-performance computing.

   Also seeing at foundries main products, leaving memory aside, foundries have added 60% of the incremental capacity in the industry for DAO and logic products during the past five years. Currently foundries account for 35% of the total industry manufacturing capacity, or 50% if memory is excluded. Their share rises to 78% in advanced (14 nanometers or below) and trailing nodes (20 to 60 nanometers) using the more advanced 12"/300mm wafer size. Furthermore, the only two companies that can currently manufacture at the leading 5 nanometer node are foundries (Antonio Varas *et Al*, 2021).

Fabless structure where technology is developed in an alliance to share high R&D costs and address time to market and time to volume challenges. In this fabless structure, EDA (electronic design automation) has emerged as a key stake-holder to model increasing design and manufacturing interface complexities and its integration within design flow, but collaboration within alliances have resulted information sharing and technology transfer as the key challenges.

The fabless-foundry market approach is driven by business decisions that maximize the profits and minimize the risks in a high-technology market that is extremely capital intensive and subject to severe industry cycles and respond to increasing globalization that started more than 20 years ago.

In terms of risk involved in changing technology, smaller design groups are naturally able to re-deploy their resources more efficiently to cope with such market risks. This combined with a reduction in transaction costs associated with information transfer from design to manufacturing, increase the attractiveness of firms to specialize in semiconductor design. In addition, increasing economies of scale in manufacturing arising from higher manufacturing investment requirements meant that risks associated with fluctuating market demand for semiconductors could be mitigated by aggregating demand from a number of smaller fabless firms. So, this bring to the emergence foundries that concentrate solely on semiconductor manufacturing. The attractiveness of the "fabless-foundry model" was self-perpetuating in that it mitigated the risks faced by design firms of losing their product marketing know-how to contract manufacturers, thereby strengthening the emergence of the foundry model.

This new business model enhances the efficiency of the semiconductor industry by effectively apportioning the risk in technology and market forces to firms that are best suited to diversify and mitigate the costs and these risks.

Fabless-foundry Osterwalder's business model canvas

1- **Key activities:** most important activities for fabless companies, in executing their value proposition, are superior design capability and solid execution. Possibility to focus only on their value add activities, designing and marketing killer chip;

2- **Key resources:** The resources that are necessary to compete in fabless market are mainly related to the human know-how, so in the selection and instruction of workforces;

3- **Key partners:** complementary business alliances as strategic alliances, are a turning point of this industry, because fabless companies have the need of long-term source of supply for dedicated design, so have the need of stable source of wafer-supply. Moreover, EDA' (electronic design automation) suppliers have emerged as a key stake holder to model increasing design and manufacturing interface complexities and its integration within design flow. Obviously, for the business model nature, the main partners are the foundries.

4- **Value propositions:** Value engineering for semiconductor manufacturing is slowly fading, giving rise to a gap that becomes mandatory for designers to think out of the box and provide higher density with multiple circuit functions, what is known today as the “System Design”;

5- **Customer segments:** fabless industry serve a market that is composed by other businesses, so is a B2B, composed by various sectors. Due to their specific know-how on leading-edge technologies, fabless companies have the possibility to focus on specific customers, searching for highly specialized technologies. So fabless companies are oriented to niche market, instead of a mass market orientation;

6- **Channels**: typical B2B channels, using local representatives/distributors and/or direct marketing;

7- **Customer relationships:** main customers, high-end electronic sector. No customer loyalty, since in this market sector, a company is able to be profitable and sustainable, only if produce new innovative products, with a constant peace;

8- **Cost structure:**

Usually, fabless companies have low marginal cost and the absence of PP&E investment. The major cost is the initial product development. Due to low variable cost in producing additional chip, the product development expense becomes one of the biggest cost component for fabless companies.

To build a new fab foundries have to justify the huge fixed initial investment. The required economics of scale in this industry are enormous.

- Economies of scale/scope

9- **Revenue streams:** leading-edge technologies, with high profit margins.

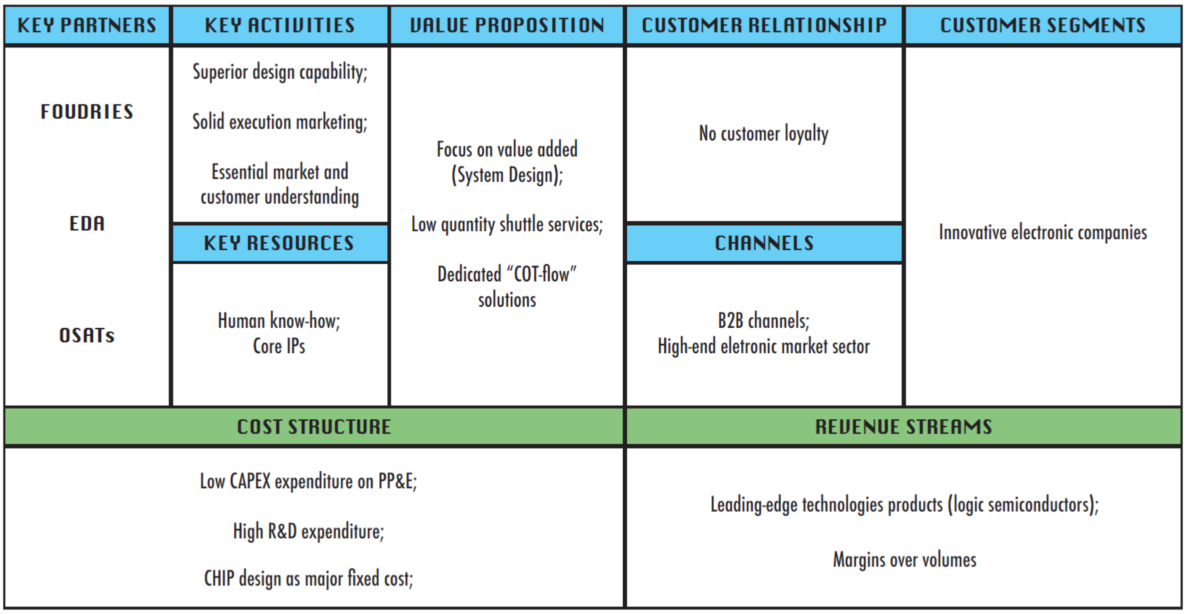

Figure 4.1 Fabless-foundry business model.

Fabless-foundry' advantages

- Ability to focus on value added, while having wide access to leading-edge technology. Upside during capacity shortages, no worry with utilization during oversupply;
- Successful fabless companies flawlessly execute a succession of enthusiastically adopted high-margin products. Their execution methodology effectively uses the optimum technology that wafer foundries can offer;
- Risk sharing. Fabless companies are risk-free in terms of the capital expenditure for building semiconductor fabrication plants. By pooling the demand from various fabless companies, foundry companies reduce the risk of rapid falls in demand caused by the sales failure of individual fabless companies. Moreover, foundry companies can provide extra capacity to IDMs that face a surge in demand or inefficient capacity. This cooperation not only allows IDMs to reduce their investment in equipment and capacity but also provides flexibility to their production;
- Operational efficiency. The fabless–foundry model shortens the cycle time from IC design to IC mass-production by using a modular design and manufacturing concept. Fabless companies can design ICs based on various component modules, most of which have been validated by foundry companies as being capable of being

reliably manufactured. This advance validation greatly reduces time to market and production costs by sharing the process development costs.

Fabless-foundry' disadvantage:

- *Foundry's influence:* dependence upon limited number of foundry partners. the top three foundries (TSMC, Global Foundries and UMC) account for more than 70% of market shares. Foundry's influence is enormous. Especially, due to process technology dependency, is not easy for fabless companies to switch foundry partner. It will take at least 6 months for fabless companies to retool IP library and process dependent parameters.

4.2 IDM business model:

IDMs have their own chip manufacturing facility, in other words they own fabs. In addition, IDMs is an integrated firm, that perform also marketing, supply chain management and after sale support. IDMs need to constantly be worried with capital expenditures for their increasing production demand, technology changes and under-capacity costs in times of declining demand.

It can be said that every minute that and IDM CEO spends in discussing the company's internal manufacturing capital expenditures requirements, is a minute not spent discussing the next product generation roadmap or a minute not spent with a prospective customer, thus in a way, taxing critical resources throughout the company. On the other hand, some IDMs have pursued this manufacturing strategy due to the belief that they can differentiate themselves in terms of a leading edge semiconductor fabrication or packaging process or technology. This differentiation is becoming less of a reason as the leading foundries are catching up in bringing leading edge technology at par with the IDMs.

IDM Osterwalder's business model canvas

1- **Key activities:** IDMs are highly vertical integrated. IDMs companies have to perform several activities, in order to deliver the product to the market: designing, testing, and building their products.
2- **Key resources:** As main resources to create value for the customer, support and sustain the business, IDMs have the FAB an IP (intellectual property);

3- **Key partners:** being a complex industry, even if IDMs are highly vertical integrated. IDMs are part of an ecosystem of enterprises, so the main partners needed are: EDA companies, OSATs, Raw materials suppliers.

4- **Value propositions:** building a fab will take resources away from semiconductor's firm most value-add function, designing and marketing chip. To most IDMs, the economic rent provided by manufacturing chip is much less than designing chip, therefore even IDMs are outsourcing the production right now.

5- **Customer segments:** IDMs' market is a B2B and most IDMs focus on general-purpose microprocessor. In this business model, design or manufacturing low-to-mid volume products are not viewed as a viable business. This organizational thinking often makes IDMs ignore the emerging market. This attitude keeps IDMs from continue investing in the follow-up product and eventually lose in climbing the S-curve;

6- **Channels**: typical B2B channels, using local representatives/distributors and/or direct marketing;

7- **Customer relationships:** IDMs focus on general-purpose microprocessor, so they serve big customers, with which have a strong relationship, being a concentrated market;

8- **Cost structure:** IDMs have to sustain huge fixed costs to build fab. The cost of running a fab is skyrocketing. The compound effect of high leverage and the expected ROI sometimes look like a poison pill.

   Huge capital investments, CAPEX (capital expenditures).

   Due to the high initial investment in fab, the business model of most IDM is to design and manufacture chips with high potential volume, therefore they can best utilize the valuable fixed asset, the fab. Indeed, currently the IDM model is more common for firms focused on memory and DAO products, which are largely general-purpose components and more scalable.

9- **Revenue streams:**

   Market power in bundling system: IDMs with dominant position in key components are likely to bundle subsystem to extract extra consumer surplus. IDMs can exercise its power in bundling manufacturing and design.

   For example Intel, in the past, bundled its CPU with associated chipset. Bundling is one form of one-stop shopping. It can simplify hardware system and accelerate customer's time to market.

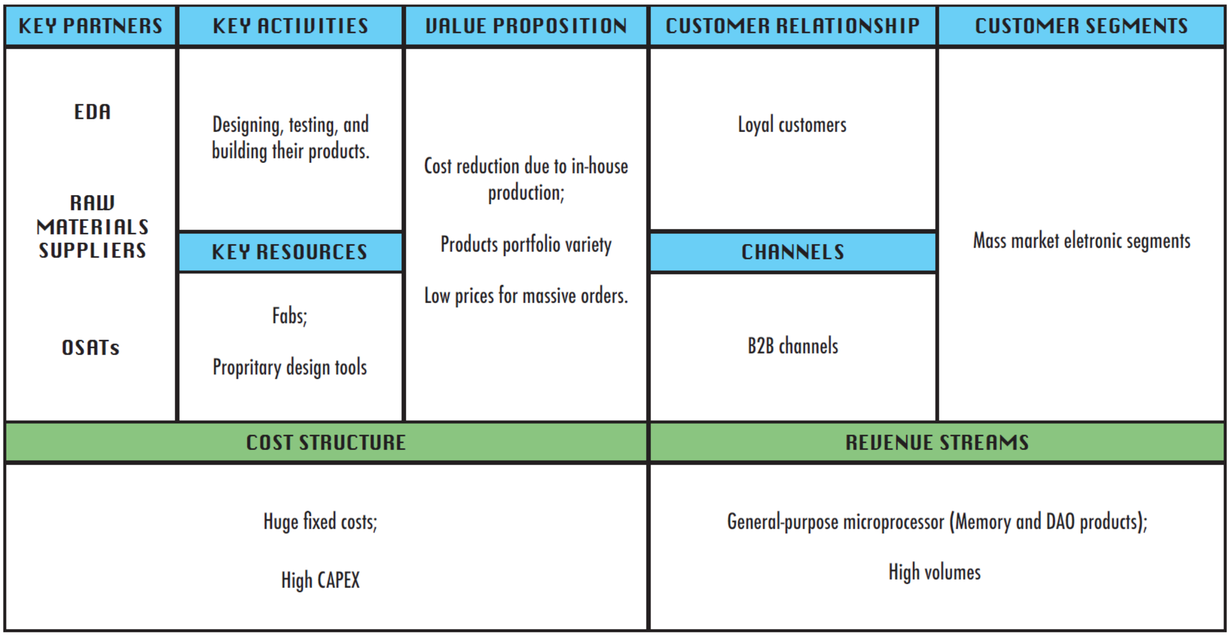

Figure 4.2 IDM's business model.

Profitability from proprietary integration

Following three examples will show how IDM benefits from their proprietary integration of manufacturing and design.

- Cost reduction: the packaging cost is rising to the point could account for more than 30% of cost to produce a chip. IDMs are able to resolve this problem through their in house patented packaging technology;
- Performance enhancement;
- New product introduction.

IDM' s advantages

- Control over their own roadmap;
- Proprietary design tools: IDMs, with their own internal chip design team and tools had the ability to model designs and work through them faster;
- Advanced process IP results from integration: as the linkage between process technology and design becomes increasingly critical, the market is transforming to a complex design, co-development service with much higher levels of interaction and collaboration. With high variety of high quality IP, system expertise and leading edge process technology, IDMs are well suited.
- Many argue that IDM model is superior to a fabless structure due to its inherent ability for faster/superior knowledge capitalization.

IDM’ s disadvantages

- Cost, risk, swings in utilization. IDMs constantly worry about the big spike in under or over capacity. Due to the difference in business model, they can’t smooth the spike by aggregating multiple external customers either.
- Need to deal with demand fluctuation. Many IDMs recognized the need and opportunity to smooth demand of fab capacity but the organization rigidity, does not help the process.
- Need to have a strong financial support;

4.3 IDM-Foundry business models differences

Fundamentally, the major difference between the IDM and fabless business models is resource control. With the IDM model, all fabrication facilities and related resources are under the direct control of a vertically integrated company. While, the fabless model is totally dependent on building complementary and lasting relationships with various suppliers.

Today, the suppliers include not only manufacturing, but assembly and test, intellectual property (IP) and EDA companies, among others.

As the process node shrink, the wafer manufacturing process experiences greater challenges to overcome, including climbing costs. As a result, more companies currently owning fabrication facilities are finding that it makes sense to outsource the fabrication process to pure-play foundries instead of equipping and maintaining older fabs with expensive, state-of-art equipment.

In this way, fabless companies minimize their financial investment by relying on third parties to develop the underlying semiconductor technology.

Fabless companies also have access to the full range of capabilities available from the entire semiconductor supply chain versus relying on the limited range of capabilities they have developed themselves (as IDMs), providing the flexibility required to truly support the needs of their customers.

Indeed, the outputs (products) coming from the two business models are quite different. How we can observe from the figure below, the three main semiconductor categories are clearly divided by the selected business model:

- IDMs: relies on general purpose products, belonging to the memory and DAO (Discrete, analog and optoelectronics and sensors) families.
- Fabless: instead, fabless companies focus on leading-edge logic products, that are the hearth of the innovative applications that are going to enlarge the semiconductor market for the next years, such as AI and high-performance computing.

Technology complexity and need for scale have led to emergence of business models focused on a specific layer of the value chain.

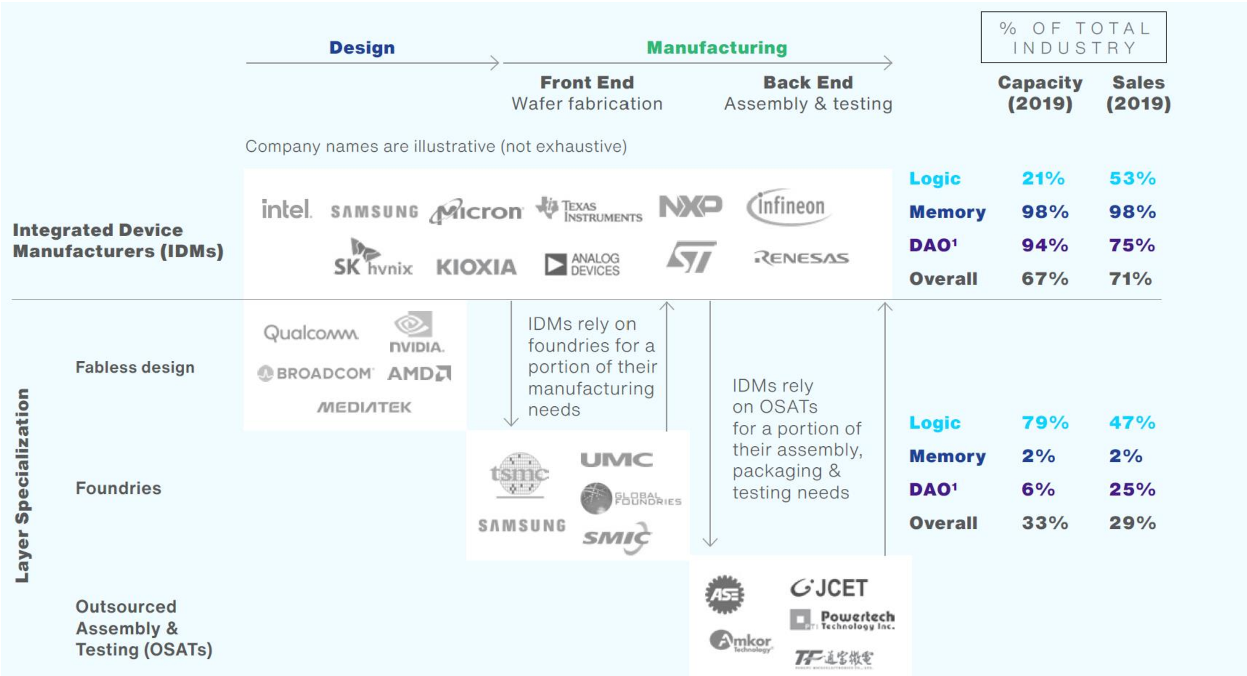

Figure 4.3 Layer specialization by business models (Antonio Varas et Al, 2021, page 24).

Indeed, semiconductor is such a complex product required sub-micron precision. All complementary technologies have to advance in the same pace. The technology and expertise involved in manufacturing a chip is completely different from that required in designing chips. Integrating these two activities into one firm (as IDM firms) increase complexity. So the increasingly specialization in every element of technology value chain makes it difficult for IDM to maintain the vertical integration.

The fabless-foundry model is a deal for anyone seeking to develop a custom IC: fabless companies are able to coordinate the efforts of a multitude of suppliers who contribute to the development of the complex product; to provide technical expertise in chip design and manufacturing and to enable purchasing leverage through the aggregation of the semiconductor supply chain. These capabilities are combined with a business model which perfectly aligns the motivations of fabless companies with their customers' urgency to get working chips to market as quickly as possible, with the lowest costs. Since the fabless-foundry model embrace the innovative nature of semiconductor, that business model, actually, is able to generate the most disruptive technologies.

The advantages of risk sharing and operational efficiency have led to the rapid expansion of the fabless–foundry model, as indicated by revenue and market share data, figure 1.21 below. From 2000s , the fabless and foundry models have grown simultaneously and the market share of IDM has declined annually. Many studies have determined that the manufacturing outsourcing business model is increasingly popular and that IDMs are adopting the fabless model.

The fabless-foundry business model constitutes a team built on partnership, and it competes with the IDM business model, which is built on ownership.

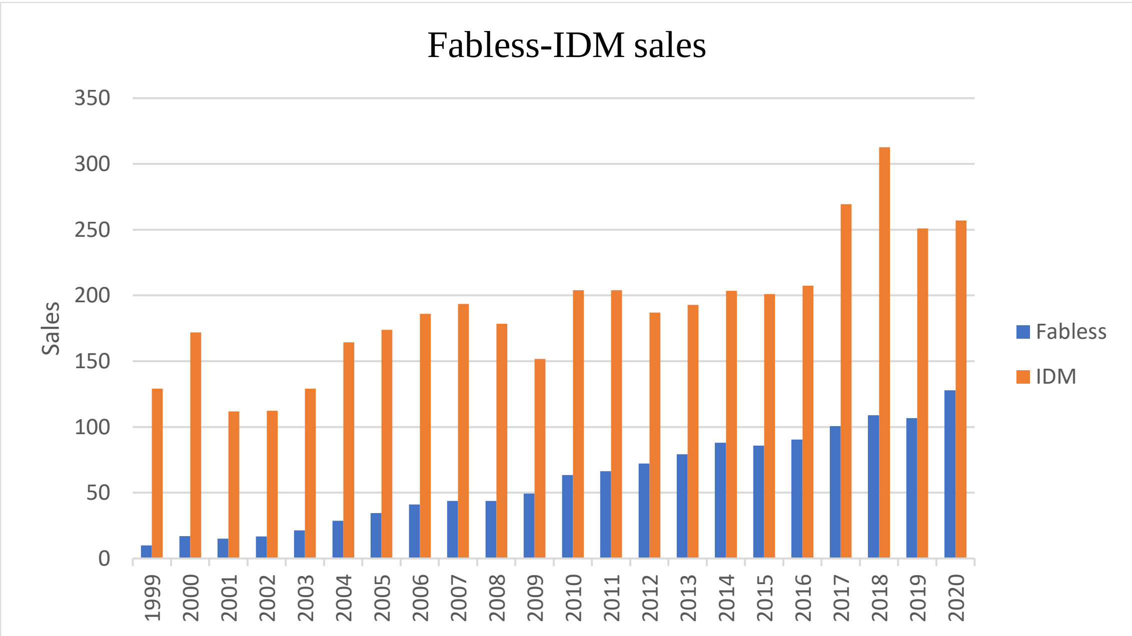

Figure 4.4 Fabless-IDM IC sales worldwide from 1999 to 2020 (in billion U.S. dollars).

(https://www.statista.com)

As shown in Figure 4.4, fabless companies are growing constantly from the end of the 20th century. These results are due to the suitability of the fabless-foundry model in a constant growing dynamic semiconductor market, that require flexible and efficient companies.

4.4 Future trends

Given the complexities and expenses associated with successfully and cost-effectively producing a leading-edge chip, there is a constant need to evaluate new approaches.

In the increasingly complex world of custom chip development, more and more companies, be they IDMs or a fabless company, will look to a trusted partner to oversee the entire supply chain in both the design and manufacturing phases of their product development, enabling them on their core value-add of developing unique approaches to system design.

IDM competes with both the fabless and foundry models, whereas the fabless and foundry models have formed a mutualistic relationship. Moreover, the growth capabilities of the fabless and foundry models are higher to those of IDM.

Semiconductor companies are facing new pressures

Fabless-foundries are facing increasing challenges upstream and downstream: the mobile-device market has become more concentrated, with Apple, Samsung and Huawei that have more than 70% of market shares. This evolution has led to concentration among mobile-chip makers (foundry customers) and has shifted bargaining power away from fabless companies.

The semiconductor-equipment industry has continued to consolidate increasing their up-stream bargaining power in most cases. Disruptive architectures and manufacturing technologies impose additional pressures on foundries.

In the area of chip design, many semiconductor companies (both IDM and fabless) are increasingly relying on external sources of technical expertise for various components of SoC design. The use of proven third-party components allows semiconductor companies to meet market pressures while continuing to focus on the components of the SoC that constitutes their core competencies. The complexity is forcing industry to look for standard components and third party collaborations.

Foundry and fabless business models will stay. The prosperity of IDMs will depend on the scale of economy and scale of fixed fab investment.

Moreover, these following trends can be observed so far:

- *Due to hold-up issues, IDM is unlikely to be success as general-purpose foundry*
  Fabless companies are competitors of IDMs, therefore it is unlikely that fabless will award manufacturing contracts to IDM's foundry; IDMs will be difficult to design

equipment and EDA tools in-house. IDMs need to work with these companies in tuning equipment and tools;

- *It is a game of racing down the learning curve (ramping up the yield rate)*

  In the past IDMs have exploited their more sophisticated know-how on production process. But in the recent years foundries have enhanced their yield rate as well.

  The solution for IDMs, to survive, is to keep innovate processes and invest in new fab. Otherwise they will have to migrate to fabless models (outsourcing part of demand to foundry, but keep advance process in-house);

- *Outsourcing will accelerate*

  Today, there are hundreds of fabless semiconductor companies, and new ones are being founded all the time. To support their growth, leading-edge wafer foundries have continued to develop and hone their skills. Going forward in today's complex and costly semiconductor environment, it is hard to imagine that a new semiconductor company could be successfully founded as a manufacturing company. The capital costs are simply too high. In comparison, the fabless-foundry business model has continued to expand, develop and prosper. As the manufacturing needs of fabless semiconductor companies have continued to increase, the wafer foundry community has continued to expand.

  Many IDMs, developed and aligned the technology with various foundry providers. This allows, IDMs to avoid duplication and reduce its research and development (R&D) costs.

4.4.1 Boundary between IDM and foundry is getting blur

Transitioning foundry business model from the pure-play manufacturing only to complete solutions provider to fabless customers

It's been more than 30 years since the foundry model revolutionized the semiconductor industry by restructuring chip manufacturing. Now the industry's ready for round two, this time they are expanding their success in other engineering functions. The conventional foundry business model established in 80's has become inadequate due to increasing manufacturing complexities with continuous scaling down of IC devices. Due these complexities, the fabless design houses require design, testing, and packaging support in addition to conventional manufacturing only support.

Big IDM firms are beefing up high-end specialized foundry business. But in the meantime, foundry also takes virtual-IDM route. For example TSMC invested in many fabless companies and design service firms. Their purpose is to expand the portfolio of process IPs and mitigate the risk of lacking process innovation associated with chip design. By the same token, foundry also team up with traditional IDMs in developing process technology through working with IDM chip design, in return, IDMs will be guaranteed to have adequate foundry capacity.

Therefore, transition of the conventional foundry business model from "pure-play" manufacturing only solution to turnkey solution provider is extremely crucial for continuous success of semiconductor business. The transition of semiconductor foundry could be achieved by collaborative efforts of foundries and their partners with complementary core-competencies such as common platform technology. Alternatively, the transition of foundries can be achieved by acquiring required core-competencies in-house. The design houses are transitioning into a system level approach to retain or increase the profit margins even further. In order to support this evolving trend of semiconductor design houses, it is crucial that the semiconductor foundries transition to complete new product development (NPD) solution provider.

With continuous miniaturization of IC devices, the complexities in IC manufacturing technology and product design are continuously increasing. Therefore, in modern foundry business model, integrated system providers are indispensable for rapid and cost-effective process and providing new solutions to Foundries' customers. As the complexities and cost in SoC design increases, the modern foundries must provide design solutions to fabless customers by acquiring new competencies in system design and developing IP to share with their customers. Thus, the modern foundries must undergo a transition from the pureplay, manufacturing-only foundry business model to solutions provider by acquiring the relevant capabilities of an IDM. This implies that the foundries must have the right IP and capabilities for design, test, and packaging along with the wafer manufacturing expertise to turn customer designs into chips that function in-system. Technology changes too fast that there is no time for outsourcing of value added product engineering.

The core competencies required for an efficient NPD support are technology CAD (Computer-Aided Design), device modeling, device characterization, circuit design, process-design-kit. These modules are designed by the manufacturers who were once a component manufacturer. These companies now exist in different shape and form. Internally, the process supports customer engineering for customers' design validation, in-house technology development and technology customization, and marketing & sales for evaluation of customers' design.

(Martin Vagues and Santosh Kumar, 2012)

5 SUPPLY CHAIN ANALYSIS

5.1 Supply Chain Framework

At the birth of the semiconductor industry (1960s), as in many other industries in that period, companies were highly vertical integrated firms (IDMs), with a low number of relationships.

Overtime, production complexity increased, requiring more specialized workers. In addition, due to the huge investment required for new processes, the industry shifted away from vertically integrated manufacturing toward a focus on core competencies, exploiting at the same time scale economy, boom-bust cycle and productivity gain realized from Moore's Law. Companies began outsourcing activities they deemed lower in value, including a new emphasis on wafer manufacturing. Semiconductor companies, started to shift investments to areas that offered a competitive advantage.

Actually, the semiconductor product complexity is so high, it is impractical and cost prohibitive for one company to handle all the processes. An ecosystem environment, where design and manufacturing tasks are handled in different locations by separate companies, means each ecosystem member can focus on its expertise, resulting in a high fragmented network of enterprises.

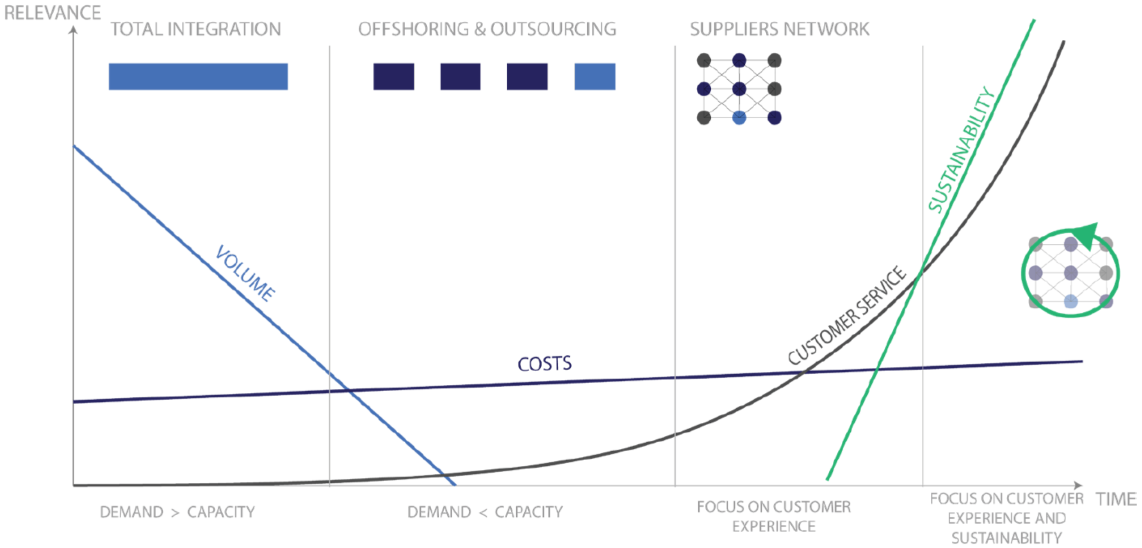

Figure 5.1: Supply chain framework

Today, the backbone of the globally integrated digital economy is the semiconductor supply chain. Specialization across the supply chain allows the deep focus required to innovate, often pushing the boundaries of science.

The semiconductor industry' companies have one of the most complex manufacturing processes and supply chains, due the high number of steps required by a single computer chip (more than 1,000 steps passing through international borders 70 or more before reaching an end customer).

Yet the fast changing market and the continuous price decrease in the semiconductor industry imposes increasing pressure on the manufacturers to decrease production lead-time, while keeping costs low. As a result superior planning capabilities across the corporatewide supply chain become more and more vital to meet the challenges of this industry.

The semiconductor supply chain stretches from fabs to back-end factories, with the intricate process of chip manufacturing sometimes requiring four to six months to complete. At the end of the line, some of the world's leading companies are waiting for the semiconductors required to launch their latest innovations. Any delays could alienate distributors and end customers, placing a semiconductor company on an unofficial blacklist.

5.2 Supply chain structure

Semiconductor supply chain network is a multi-tiered supply chain with multiple layers controlled by the same organization, in case of an IDM or by a multitude of organizations in case of Fabless companies. These supply chains comprised more than thousands suppliers in over 100 countries.

The structure of the semiconductor supply chain is influenced by several characteristics. First, the ratio of value to volume of the product is very high, therefore transportation even over long distances e.g. by plane is not an issue. Second, the equipment necessary for production is expensive and difficult to transport and install. Furthermore, the production process can be split over several locations, e.g. the facilities wafer fabrication and wafer-test/ sawing in Europe and the facilities die bonding, wire bonding, molding and chip-test in Asia. The production sites for the different stages of the production process can therefore be placed all over the world to achieve goals like reduction of costs for real estate, equipment or wages.

The global semiconductor supply chain based on geographic specialization has delivered enormous value for the industry

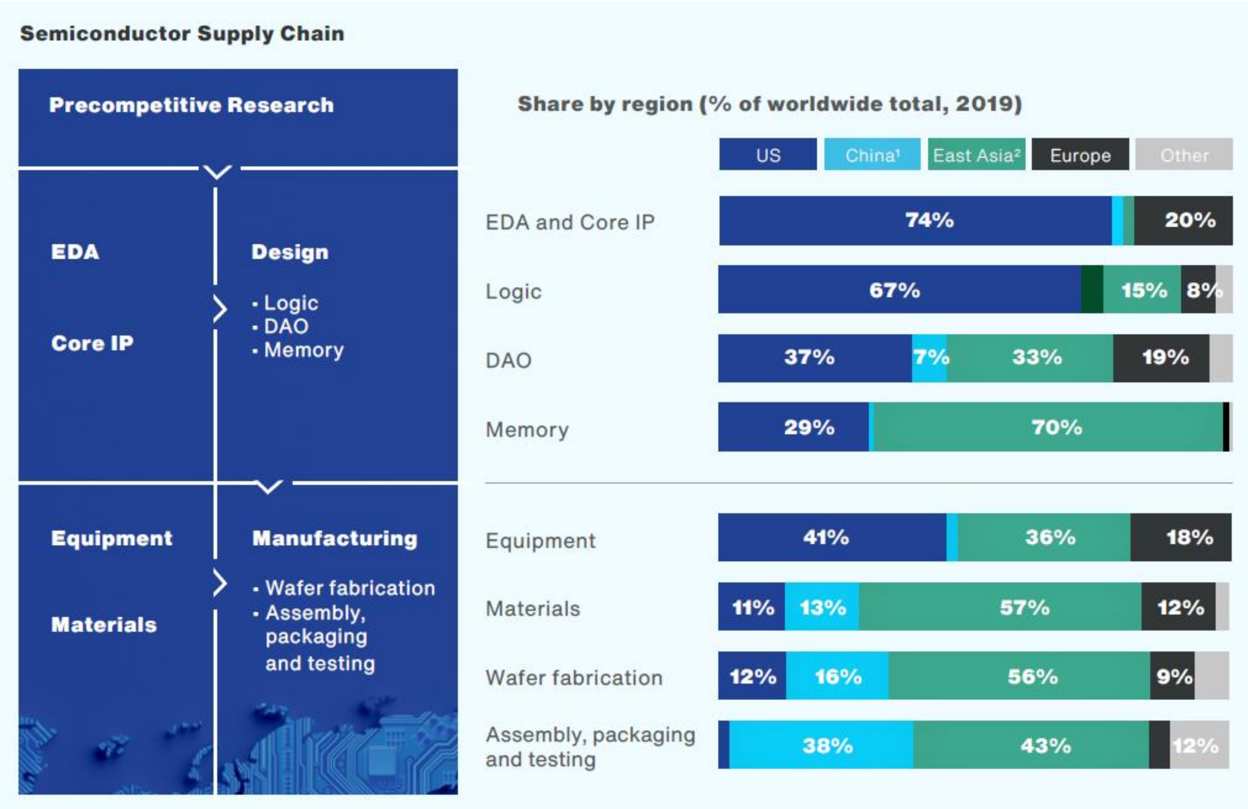

Figure 5.2: Semiconductor supply chain share by region (Antonio Varas *et Al*, 2021, P. 5)

1. Mainland China 2. East Asia includes South Korea, Japan, and Taiwan

The semiconductor supply chain is truly global: six major regions (US, South Korea, Japan, mainland China, Taiwan and Europe) each contribute 8% or more to the total value added by the semiconductor industry in 2019.

At a high level, the supply chain includes seven sectors (Figure 5.2).

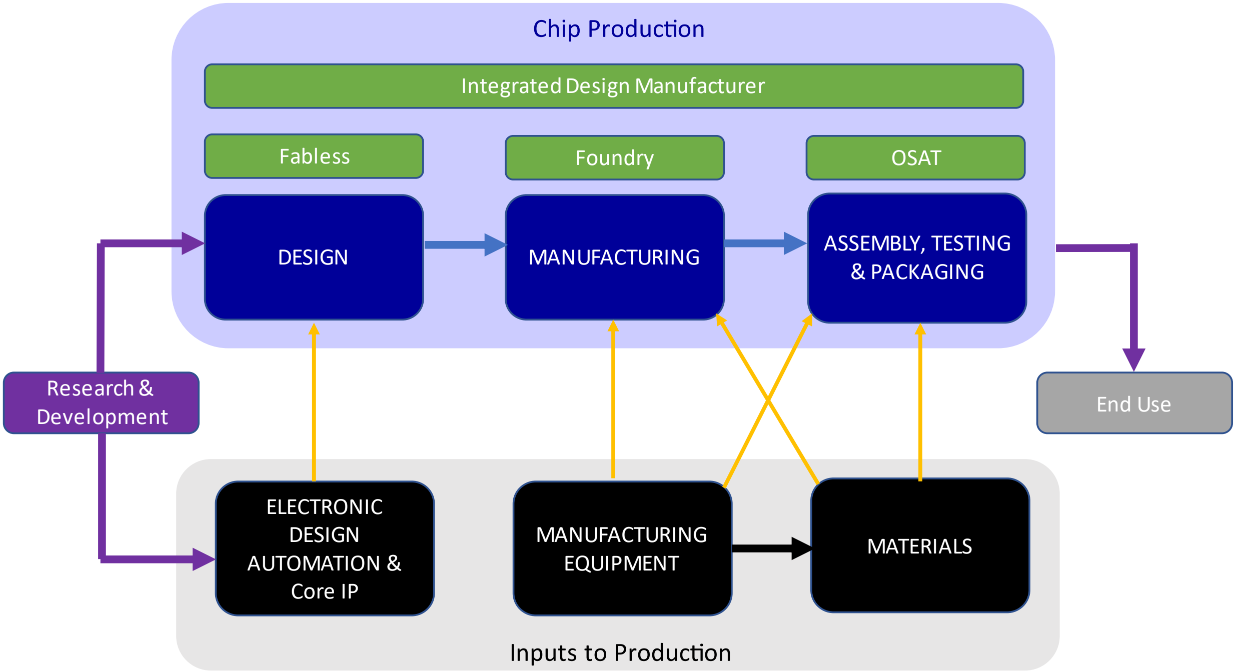

Figure 5.3: Semiconductor supply chain

While proximity to customers is clearly a significant driver of the global, interdependent structure of the semiconductor supply chain, there are three additional key factors:

- *Global R&D networks*

  International collaboration has allowed multinational companies, universities and institutions to collaborate and pool resources. Together, they undertake pre-commercial research to pursue scientific breakthroughs that lead to major leaps in semiconductor technology. A significant portion of the R&D investment by the semiconductor industry is in fundamental research into science breakthroughs, invested many years ahead of potential commercial application. Semiconductor firms and institutions such as universities and government-funded advanced science labs typically collaborate on this precompetitive research to share the costs of research and avoid duplication of efforts.
- *Geographic specialization*

  Regions are focused primarily on different activities within the semiconductor supply chain. This regional division of tasks has been driven by comparative advantage developed over the past decades of the industry's history.
- *Trade liberalization*

Global trade policies enable participants in the semiconductor industry to move goods, equipment, capital, IP and talent across borders, effectively supporting the geographic specialization across the semiconductor supply chain.

Need for deep technical know-how and massive scale have created a highly specialized global supply chain

5.3 PUSH-PULL Supply chains

Supply Chain strategies can be generally categorized as

- Push;
- Pull;
- Push-pull.

Seeking for lower supply chain cost and better on-time delivery service.

The push-pull supply chain strategy "pushes" the goods into a strategic inventory buffer, the inventory/order (I/O) interface (a more accurate term for the so-called push-pull boundary), through some initial stages, and employs a pull strategy awaiting customer orders to drive the remaining stages.

Ultimately, any supply chain system can be considered a push-pull system; it just depends on where the I/O interface is located. If the interface is at the beginning of the total process, it is a pull system; if at the end, push.

The core production-distribution supply chain of a typical semiconductor manufacturer consists of three major stages:

1- Wafer fabrication and probe;
2- Assembly and test;
3- Product delivery.

In today's global manufacturing environment, these stages (or sub stages) are often geographically distributed and sometimes outsourced.

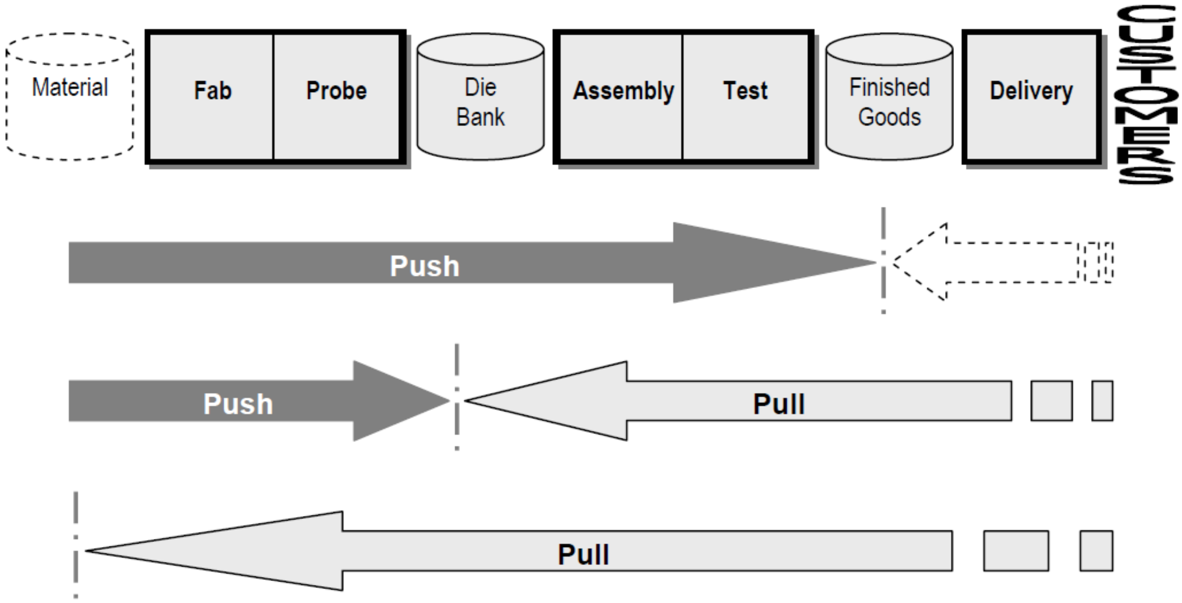

Figure 5.4: The push, push-pull, and pull semiconductor supply chains (Esma S. Gel *et Al*, 2010, page 4).

Die-bank, a typical I/O interface in a semiconductor supply chain, sits between the front-end and the back-end to store fabricated wafers. Under a pure push strategy, semiconductors are built-to-stock to final products. Under a pure pull strategy, production is not started until real demand occurs, thus semiconductor devices are built-to-order. A common push-pull strategy produces wafers with generic parent dies in the front-end and the wafers are pushed into die-bank inventory. When demand occurs, the parent dies are pulled from the die-bank and assembled-to-order in the back-end to create different final products.

(Esma S. Gel *et Al*, 2010)

5.3.1 Order fulfillment strategy

Going more in depth, a semiconductor foundry is essentially a make-to-order (MTO) factory that manufactures semiconductor products designed by customers. Yet, in a low-demand season, it may enter into a hybrid business model—producing make-to-stock (MTS) as well as MTO products to maintain high utilization of machines. Hybrid MTO/MTS system with machine-dedication characteristics, a constraint imposed on the process route caused by the advance of manufacturing technology. The scheduling method aims to achieve a high on-time delivery rate for MTO products as well as a high throughput for MTS products.

In low-demand seasons, the MTO orders may be so low that a substantial amount of capacity becomes idle. This may lead to a higher production cost and result in undesirable loss in financial statements because semiconductor manufacturing is very capital-intensive. Some semiconductor foundries may thus include the production of make-to-stock (MTS) products to increase capacity utilization.

Such a hybrid production system is called a hybrid MTO/MTS semiconductor fab. Semiconductor manufacturing has two distinct points: a long process route with re-entry characteristics and an ongoing advance of manufacturing technology. The process route of a semiconductor product may involve over 500 operations; a workstation has to process several operations on the same wafer; therefore, a job (also called a lot) has to re-enter a workstation several times. The advance of semiconductor manufacturing technology is measured by the dimension of devices manufactured.

There are some production constraints, due to quality restriction require in semiconductor manufacturing, that represents a bottleneck.

The main drivers to assign suitable production strategies to products are the characteristics of the semiconductor industry already described together with the aim to improve the performance in terms of costs and customer service.

Considering make-to-order (MTO), assemble-to-order (ATO), and make-to-stock (MTS) as production strategies. Products are produced forecast-driven until they are completely finished in the case of MTS. In the case of ATO, products are produced forecast-driven until the point right before it comes to the assembly. Starting from there, the production continues based on a customer order. The MTO strategy is characterized by an order-driven production.

Considering a simplified semiconductor supply chain, it consists of:

- A raw wafer storage;
- A fronted facility
- A die bank(DB), to store semi-finished products;
- A back-end facility;
- A distribution center, for finished products.

The frontend and the backend facility have machines and operators as resources. Our supply chain model consists of two sections. The first section consists of a production in a frontend facility and a transport from the frontend to the DB, while the second section includes the transport from the DB to the backend facility, the backend production, and the transport from the backend to the distribution center. The overall situation is shown in Figure below #.

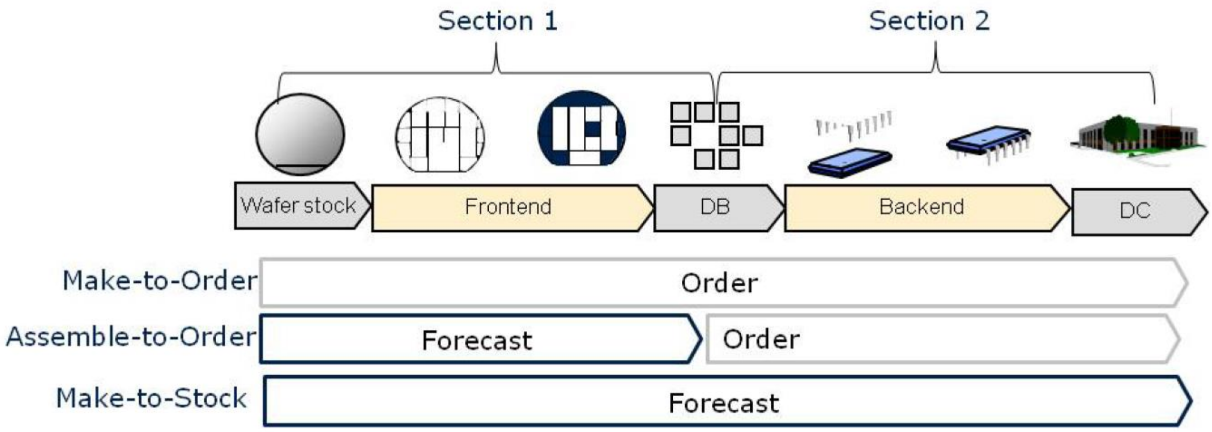

Figure 5.5: Base system of the simplified supply chain (Lisa Forstner and Lars Mönch, 2013, page 3697).

MTO products are only produced based on orders from raw wafer storage until the distribution center. ATO products are produced forecast-driven until the DB. But if orders exceed the forecast we allow to produce these orders as well. From DB, arriving customer orders enable to continue production until the end. MTS products are produced forecast-driven along the entire supply chain (see Figure 5.5).

The selection of the best suitable strategy

The selection from push, push-pull, and pull strategies for designing a semiconductor supply chain, has the goal of reducing supply chain cost and improving on-time delivery service.
Two major factors are considered to make the MTO, ATO, and MTS decision:

1- Production lead time to order lead time (P/D) ratio;
2- Relative demand volatility.

(Lisa Forstner, Lars Mönch, 2013, Page 3699)

When the production lead time is smaller than the order lead time and the demand volatility of this product is high then the MTO production strategy is chosen for the corresponding product.

If the production strategy of a product is MTO, the gross demand is calculated based only on orders for the frontend and backend section. The gross demand for the backend section is based on orders in case of ATO, while the gross demand for the frontend section is based on forecasts in the ATO setting. For MTS, the gross demand is calculated based on forecasts.

In case of low utilizations, MTS production seems to be more appropriate. While high utilizations whereas, drive the decision more towards the MTO direction in order to reduce the overall load situation.

In general, the push strategy always outperforms push-pull and pull when customers require short lead times; push might perform worse than the other strategies with long quoted lead times.
The different strategies consider the impact of different relative demand volatility on the selection of the production strategy. For a low relative demand volatility the preferred strategies are MTS and ATO. The amount of products that are produced by a MTO strategy increases slightly for larger demand volatility values.

The different product characteristics affect the selection of the production strategy as well. Each product has different characteristics such as expected revenue, order lead time, and the over and under estimation of the final demand by the forecast. In general, products with a short order lead time tend to be produced using the MTS or the ATO strategy, while products with a low expected revenue are more likely produced using MTS compared to products with a high expected revenue.

To conclude the two main production strategies are explained:

MTO (Make-to-order) leading-hedge logic chips:

- Long lead time;
- High expected revenue;
- Low manufacturing variability.

MTS (Make-to-stock) DAO and memory products:

- Very short order lead time;
- Low expected revenue;
- High manufacturing variability.

To conclude, Fabless-foundry companies are used to select the MTO production strategy, while IDMs find more advantages in the MTS strategy.

5.4 Competitive factors

In order to evaluate the semiconductor supply chain characteristics, this paragraph gives insights about the latest customer requirements.

In today's semiconductor industry, the lead time, as well as the perceived importance of on-time delivery, are the primary driving factors for choosing the strategy, while demand pattern and process variability need to be considered as secondary factors.

Demand pattern and process variability are also of great importance. For instance, instead of using the demand information aggregately, it is reasonable for a semiconductor vendor to satisfy "tough" customers that always place orders with very tight due-dates with a push strategy, and to satisfy "easier" customers with a push-pull or even a pull strategy. Different combinations of strategies can also be adopted for different mixes of products.

The use of a die-bank is popular today. However, it is not the only solution for locating the I/O interface in the semiconductor supply chain. For example, strategic inventory can be held before the interconnection process in the wafer fab. The dies can be interconnected differently to produce different products when a real order comes in to indicate which final product is demanded. Such a choice typically involves technical complications. In this example, semiconductors designed for multi-interconnection typically require a larger die-area leading to fewer dies per wafer (higher cost per product).

On-time delivery—a priority for customers

When it comes to customer retention, supply-chain performance matters. That much became clear when we asked managers at six major semiconductor customers and distributors to rate the factors that influenced their purchase decisions on a scale of one to ten, with ten being the most influential. Product specifications, which include quality and features, ranked first, but On-Time-Delivery tied price for second (Exhibit 5.7).

Interview subjects frequently noted that they gave preference to semiconductor companies with a strong OTD record. One said, "For suppliers with good delivery performance, we invest more, as we feel more comfortable that we can deliver the products to our own customers" (Gaurav Batra *et Al*, 2018, Page 2).

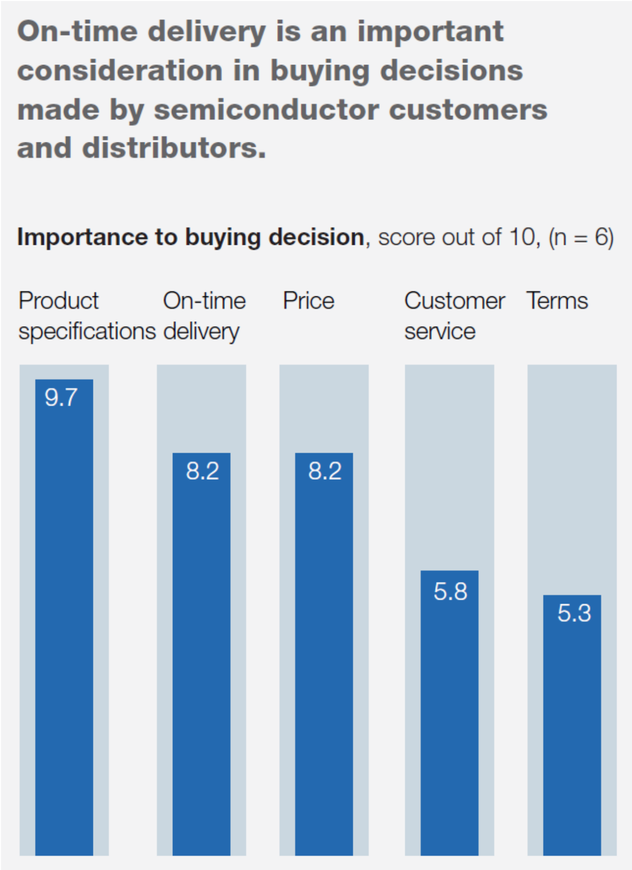

Figure 5.6: On-time delivery is an important consideration in buying decisions made by semiconductor customers and distributors (Gaurav Batra *et Al*, 2018, Page 2).

In semiconductor industry late shipments are common.

Supply chain metrics should focus on detailed insights into the end-to-end performance of the supply chain. For each order, supply chain management has to concentrate on:

- Accuracy in demand forecasting, to deliver the right product;
- Execution schedule rigidity, all tasks to be completed at the right time;
- Inventory staged along the supply chain at the right locations.

With the focus on these stages, companies can identify all root causes behind performance issues.

What's behind the low On-Time-Deliveries rates?

When semiconductor companies receive an order, they have chips at every stage of the supply chain, with some undergoing front-end processing, others in die-bank or back-end processing, and the remainder sitting in warehouses as finished goods. Likewise, the lead times for orders may vary, with some customers expecting quick shipments and others requesting deliveries along a more relaxed timeline.

All too often, however, semiconductor companies discover that the requested lead time is shorter than the cycle time needed to fulfill the order. Most missteps that lead to late deliveries relate to one of three areas: forecasting, execution, and inventory. For instance, if the order lead time is shorter than the three to four weeks required for back-end processing, a semiconductor company must have sufficient finished-goods inventory to meet the target delivery date. But many players inaccurately forecast future demand and don’t have enough finished goods in stock when such requests arrive.

6 SEMICONDUCTOR SUPPLY CHAIN MAP

The semiconductor supply chain, is a specialized global supply chain, in which regions perform different roles according to their comparative advantages.

6.1 Sourcing, making and delivering

To better understand the semiconductor supply chain, below a summary version of the supply chain map about semiconductor. Supply chain maps can be summarily described by three main subjects:

1- Suppliers:
2- Producers;
3- Customers.

6.1.1 Sourcing

All the inputs to production, required in the semiconductor production process, be either direct raw materials or intangible inputs.

EDA & Core IP:

The United States is the dominant producer of electronic design automation software, and the United States and the United Kingdom are dominant producers of core intellectual property. These interrelated inputs into chip design are both key chokepoints for China.

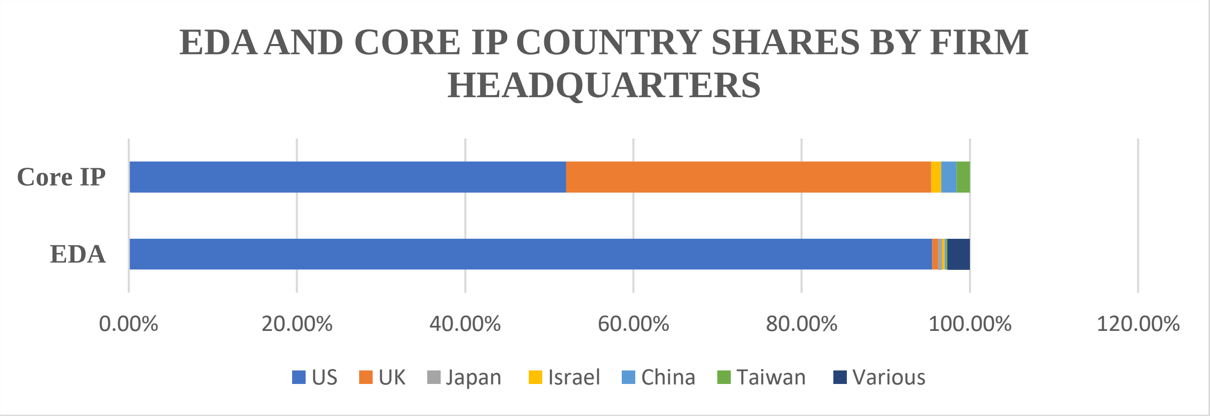

Figure 6.1: EDA and core IP country shares by firm headquarters (Saif M. Khan *et Al* 2021)

EDA software: U.S. firms are the exclusive providers of EDA software with the full-spectrum capabilities needed by engineers at fabless firms and IDMs to design leading-edge chips. U.S.

firms also dominate capabilities relevant to AI chip design, such as ASIC layouts. Although the industry is top-heavy, startups frequently enter the EDA space. However, they struggle to compete with top EDA firms that typically acquire them to incorporate the startups' niche functionality to their full-spectrum capabilities. Leading chipmakers Intel, Samsung, and TSMC give the top U.S. EDA firms, such as Synopsys and Cadence, preferential access to process IP during the development of new manufacturing processes.

Core IP: Chip design firms license core IP, which consists of reusable design blocks, and incorporate it final chip designs. U.S. and U.K. vendors dominate the market. Some firms specialize exclusively on core IP, such as U.K.-based, Japanese-owned ARM, while others combine their offerings with EDA tools. ARM is the top core IP vendor, providing an instruction set architecture (ISA) and associated core IP underpinning most of the world's smartphone processors.

***Manufacturing equipment**:*

The United States, Japan, and the Netherlands dominate the production of manufacturing equipment, crucial technologies, for example the most severe chokepoint in China's chip supply chains. There are dozens of categories of semiconductor manufacturing equipment. Most Semiconductor Manufacturing Equipment is used for making chips or inputs to them. These tools include those for wafer manufacturing, wafer and photomask handling, wafer marking, ion implantation, lithography, deposition, etch, clean, chemical mechanical planarization, and process control. Specialized tools are also used for assembly, testing, and packaging.

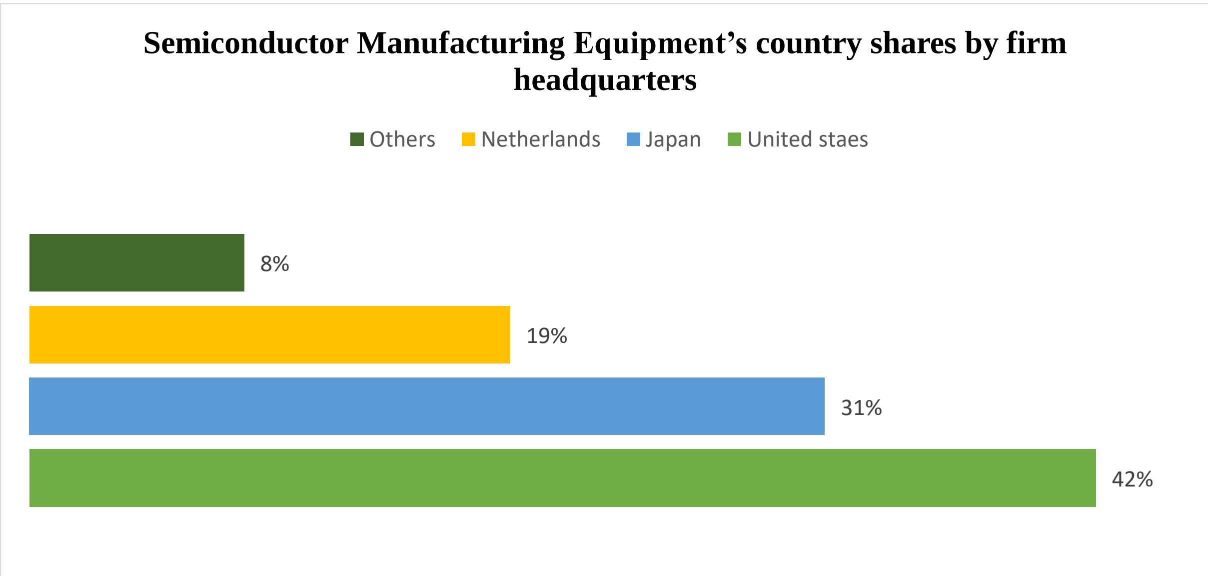

Figure 6.2: Semiconductor Manufacturing Equipment's country shares by firm headquarters (Saif M. Khan *et Al* 2021)

Japan, China, Singapore, the United States, and a number of other countries produce assembly and packaging tools, taking a wafer with completed, unseparated chips and turning it into separate, packaged chips.
Japan, the United States, and South Korea produce most testing tools.

Materials

Firms involved in semiconductor manufacturing also rely on specialized suppliers of materials. Semiconductor manufacturing uses as many as 300 different inputs, many of which also require advanced technology to produce. Each semiconductor materials segment takes raw materials as inputs.

Raw Materials

China is the world's breadbasket for raw materials, while the United States and its allies together also produce a sizable share of nearly all materials. Given the complexity of semiconductor fabrication, the raw materials that go into these segments span a large portion of the periodic table. These raw materials largely covers the most key non-gaseous materials, but not exhaustively. "Primary" production refers to mining of materials, especially low-grade materials before processing into high-grade materials or into compound forms.

China has the largest share for most materials, and a significant share for all. The United States produces a small amount of most materials. China has a 64% production share for silicon—the most widely used material—but the United States and its allies have large reserves. Although China no longer holds monopoly on rare earth mining, it still dominates rare earth processing.

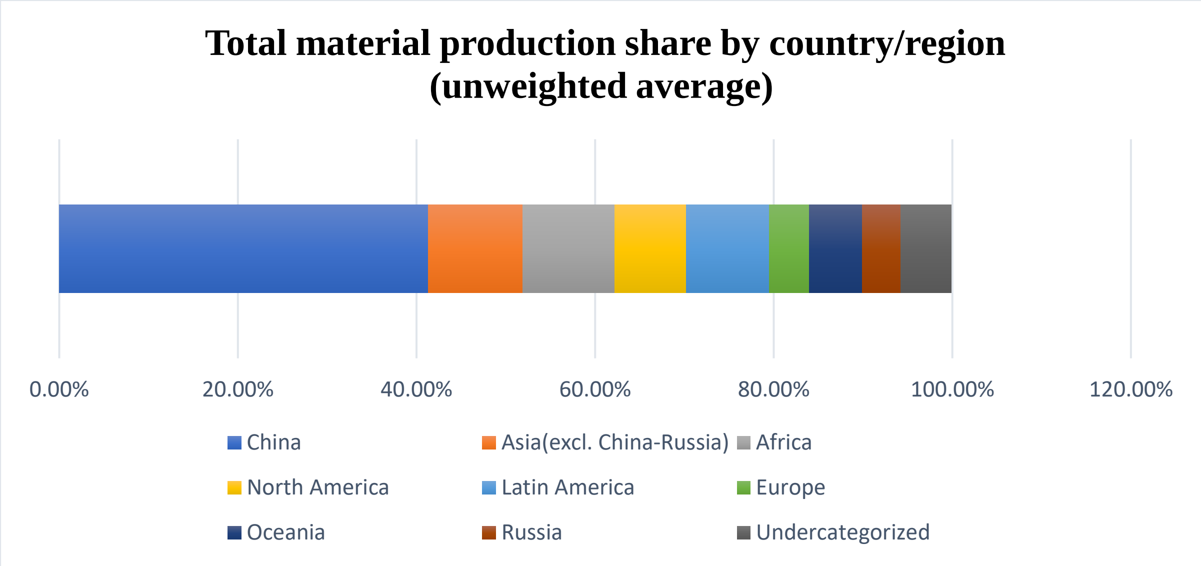

Figure 6.3: total material production share by country/region (unweighted average) (Saif M. Khan *et Al*, 2021)

Figure 6.4 takes an unweighted average of production shares of all of these materials and presents regional production shares.

Chinese firms are dominant suppliers of raw materials, but face multiple chokepoints in the production of manufactured materials (which take many materials as inputs) used in semiconductor manufacturing.

Chokepoints include advanced 300 mm wafers, photomasks, and photoresists. Meanwhile, the United States has a small domestic production capacity and relies heavily on imports of raw materials, but does have meaningful market share across semiconductor material segments.

The production stages include materials used in the production of wafers (predominantly silicon wafers), fab materials used to manufacture chips, and packaging materials.

Semiconductor raw materials can be divided, in two main categories:

1- *Front-end materials:* those used for the wafer fabrication. Japan, the United States, Taiwan, South Korea, and Germany are key producers of fab materials.

   The main front-end materials include:

   Polysilicon: is a metallurgical grade silicon in ultra-refined purity levels, suitable for use in semiconductor wafer production.

   Silicon wafers (36%): Polysilicon is melted, formed into single crystal ingots which are then sliced into wafers, cleaned, polished, and oxidized in preparation for

circuit imprinting within fabrication facilities. Firms headquartered in Japan, Taiwan, Germany, and South Korea
are top producers of wafers (Figure 6.4).

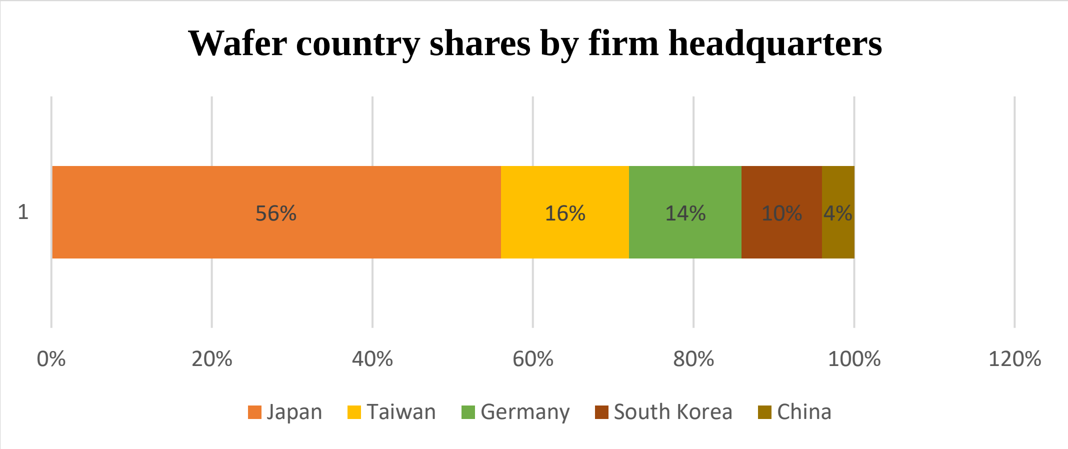

Figure 6.4: Wafer country shares by firm headquarters (Saif M. Khan *et Al* 2021)

Wafers are thin, disc-shaped materials on which chips are fabricated.
Most wafers are made purely of silicon or another material, but others have more complex structures. Dopants are materials added to wafer materials (like silicon) to give them a level of semi conductivity suitable for transistors in chips to operate correctly. Wafer producers headquartered in Japan, Taiwan, Germany, and South Korea make state-of-the-art 300 mm diameter wafers, which are used for 99.7 percent of the world's fab capacity capable of manufacturing chips at ≤45 nm nodes.
Photomask (12%): A plate covered with patterns used in the lithography process. The patterns consist of opaque and clear areas that prevent or allow light through. Japan, the United States, Taiwan, and South Korea lead production of leading-edge photomasks (e.g., ≤16 nm), which China does not produce.

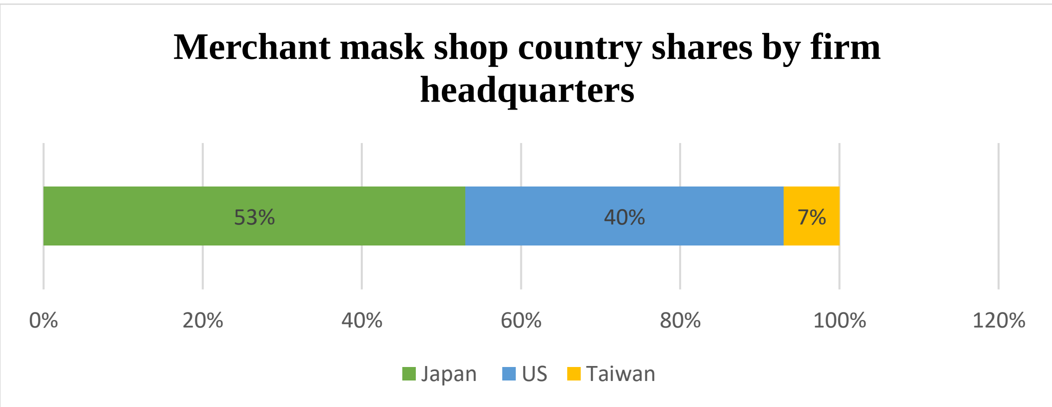

Figure 6.5: Merchant mask shop country shares by firm headquarters (Saif M. Khan *et Al* 2021)

Photoresist (13%): A special material that undergoes a chemical reaction upon exposure to light. Silicon wafers are covered with a photoresist layer, which is imprinted with the patterns contained in the photomask during the lithography process. Japan dominates the production of semiconductor photoresists with 90 percent market share, with the remainder largely held by U.S. and South Korean firms.

Wet processing chemicals (7%): Used in the etching and cleaning steps of the semiconductor manufacturing process, and include solvents, acids, etchants, strippers and other products.

Gases (16%): used to protect wafers from atmospheric exposure. Other gases are used in the semiconductor manufacturing process as dopants, dry etchants, and in chemical vapor deposition (CVD).

Chemical Mechanical Planarization (CMP) slurries (7%): materials used for polishing the surface of the wafer after the film deposition step to provide a flat surface.

2- *Back-end materials:* those used into for the assembly, packaging & testing. Include lead frames, organic substrates, ceramic packages, encapsulation resins, bonding wires and die-attach materials. The organic substrate accounts for the 48% of the total back-end materials.

They typically have relatively lower technical barriers to produce compared to the wafer fabrication materials.

Japan leads production of packaging materials, while other countries including the United States and China also have market shares.

Packaging involves several steps to bond a fabricated chip to an encasing package.

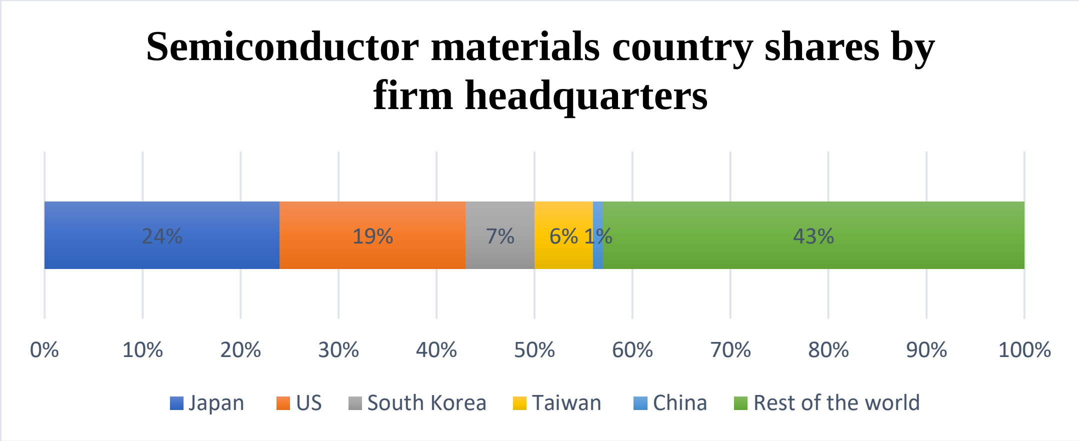

Figure 6.6: Semiconductor materials country shares by firm headquarters (Saif M. Khan *et Al*, 2021).

From the analysis above is stated that, the main supplier of materials used to manufacture semiconductor products, is the Japan followed by United States and other Asian countries.

6.1.1 Making

Processes that transform semiconductor products to a finished state to meet planned or actual demand.

Design

The United States, South Korea, Europe, Japan, Taiwan, and China perform almost all of the world's semiconductor design. The United States leads in logic and analog chips, South Korea in memory chips, and Europe in discrete chips. China designs many logic chips—though most of its chips do not compete with state-of-the-art U.S. chips—and some discrete ones;(The market shares and sizes are for semiconductor sales, which include value-add from steps besides design. However, because the same firm typically designs and sells a semiconductor—even if it often outsources fabrication and ATP—these market shares correlate well with shares in design activities.) This section focuses on certain high-end logic chips and the most common memory chips.

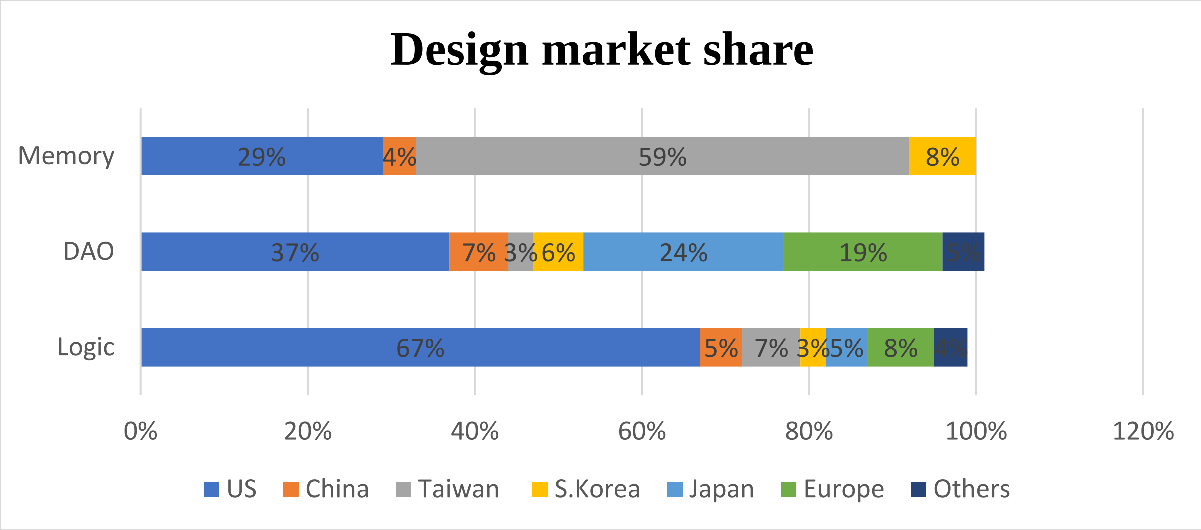

Figure 6.7: Design market share (Antonio Varas et Al, 2021)

Manufacturers

Firms headquartered in the United States, Taiwan, South Korea, Japan, and China control the vast majority of the world's fab market share (Figure 6.8) and fab capacity. Advanced logic capacity represents China's greatest weakness in fabs, though it is attempting to build such capacity. Firms headquartered in the United States, Taiwan, South Korea, Japan, and China control most of the world's logic capacity. Three firms – headquartered in the United States (Intel), Taiwan (TSMC), and South Korea (Samsung) – control virtually all of the world's advanced logic fab capacity (≤10 nm), though U.S.-based Intel is building such capacity in Israel and Ireland.

Three firms – headquartered in the United States (Intel), Taiwan (TSMC), and South Korea (Samsung) – control virtually all of the world's advanced logic fab capacity (≤10 nm), though U.S.-based Intel is building such capacity in Israel and Ireland.

In fabrication, which is extremely capital intensive, the availability of attractive investment conditions – particularly government incentives – and access to robust infrastructure (power and water supply, transportation and logistics) and a skilled manufacturing workforce at competitive rates have traditionally been the key success factors. Government incentives may account for up to 30-40% of the 10-year total cost of ownership (TCO) of a new state-of-the-art fab, which is estimated to amount to $10-15 billion for an advanced analog fab and $30-40 billion for advanced logic or memory.

The East Asia region (including Japan, South Korea and Taiwan) and mainland China currently concentrate about 75% of the world's total semiconductor manufacturing capacity– including all the leading edge capacity at 7 nanometers and below currently in operation – and under current market conditions its share is expected to continue rising over the next decade. The TCO of a new fab located in the US is approximately 25-50% higher than in Asia, and 40-70% of that difference is attributable directly to government incentives, which are currently much lower in the US than in alternative locations.

In particular, Taiwan has been investing in the development of its domestic semiconductor manufacturing industry since 1974, when the government selected semiconductors as a key focus industry to expand the economy beyond agriculture.

While several of the incentive programs were reduced after 2009-2010 by the Taiwan's government, estimations today say that Taiwan still provides incentives for new fabs worth 25-30% of their overall total cost of ownership over a 10-year period. This is in line with other Asian locations such as South Korea and Singapore, but currently well below mainland China. In contrast, the incentives to new fab construction currently available in the US and Europe are estimated to reach just 10-15% of the total cost of ownership.

Today, Taiwan is home to 2 of the 5 largest foundries globally and hosts 20% of the total global capacity. Along with Intel (US) and Samsung (South Korea), TSMC is one of three firms that can produce logic chips in advanced nodes (10 nanometers or below), which are required for compute-intensive devices such as data center/AI servers, PCs, and smartphones. In fact, almost all of the world's capacity in the leading nodes (5 and 7 nanometers) is located in Taiwan (Exhibit 6.8).

East Asia + China concentrate about 75% of the wafer fabrication capacity; in particular, all advanced logic capacity < 10nm is currently located in Taiwan and South Korea.

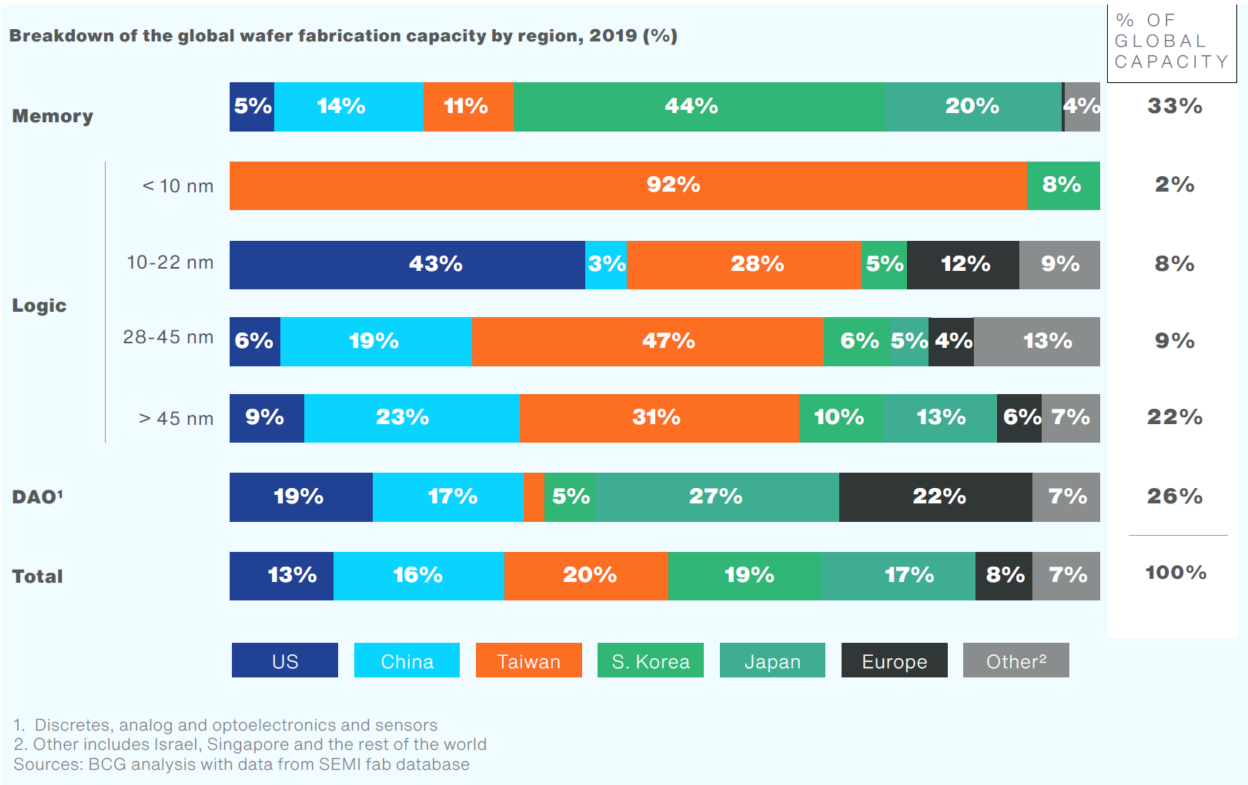

Figure 6.8: Breakdown of the global wafer fabrication capacity by region (Antonio Varas et Al, 2021, page 35).

US leads in R&D intensive activities, supported by its "talent magnet", Asia leads in capital intensive activities, supported by government incentives.

Assembly, testing & packaging

ATP activity is labor-intensive and lower value than design and fabrication, and does not develop skills in these two segments. Therefore, firms historically set up ATP facilities in developing countries. Firms headquartered in Taiwan, the United States, China, and South Korea are the main providers of ATP services (Figure #). China benefited from offshoring, developing a strong ATP industry—its OSAT industry is the world's second largest after Taiwan. Additionally, non-Chinese IDMs keep many ATP facilities in China. Although the top three ATP firms in China are Chinese OSATs, the rest of the top 10 are non-Chinese IDMs (six American). Therefore, ATP is arguably a supply chain vulnerability for the United States. Overall, 22% of the world's ATP facilities are in China.

Although ATP was historically low value, packaging has increasingly become a bottleneck on chip performance. Densities of transistors in logic and memory units in chips have continued to increase exponentially, but the density of interconnects between logic and memory—

governed by packaging—have increased at a much slower rate, leading to communication bottlenecks between chips. Additionally, the rates of increases in density of logic and memory may slow providing comparatively more innovation opportunities for advanced packaging.

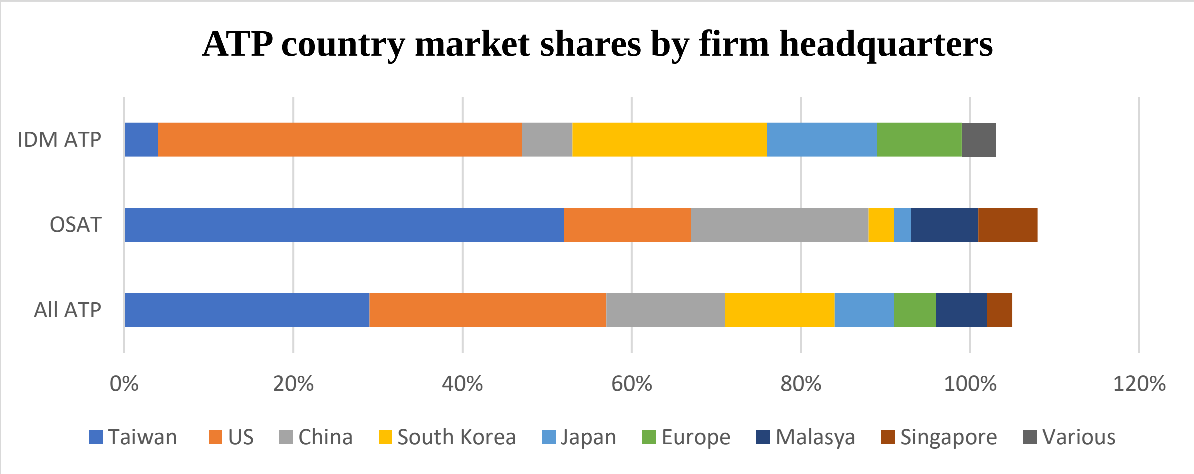

Figure 6.9: ATP country market shares by firm headquarters (Saif M. Khan *et Al* 2021).

Compared to manufacturing, assembly, packaging and testing is much less capital intensive. While the annual capital expenditure of foundry companies is typically around 35% of their revenues, for leading firms specializing in outsourced semiconductor assembly and testing (OSATs) capital expenditure typically runs at less than half of that level, at approximately 15% of their revenues. Given the lower capital intensity, the cost of labor is a key competitive factor for OSAT firms. According to data from the "Conference Board: International Comparisons of Hourly Compensation Costs in Manufacturing", 2018 , the average manufacturing wages for skilled labor in mainland China, Taiwan and Southeast Asian countries such as Singapore and Malaysia are up to 80% below US levels. Today 9 of the 10 largest OSAT firms by revenue are headquartered in mainland China, Taiwan and Singapore. In terms of capacity location, mainland China and Taiwan account for more than 60% of the world's assembly, packaging and testing capacity. Recently OSAT firms have also started to diversify their own global footprint, building new capacity in other locations with low labor costs such as Malaysia. However, with the increasing level of technology innovation in the field of advanced packaging, labor cost may become less of a decisive factor going forward.

6.1.2 Delivering

Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management.

Following the a global journey of a smartphone application processor, the last step is: the shipment of the chip to the smartphone OEM's assembly partner in China, who incorporates it into a circuit board inside the phone. This example, is made to practically explain which is the biggest final market for the semiconductor industry, since semiconductor products are mainly embedded in electronic devices, which are manufactured mainly in China.

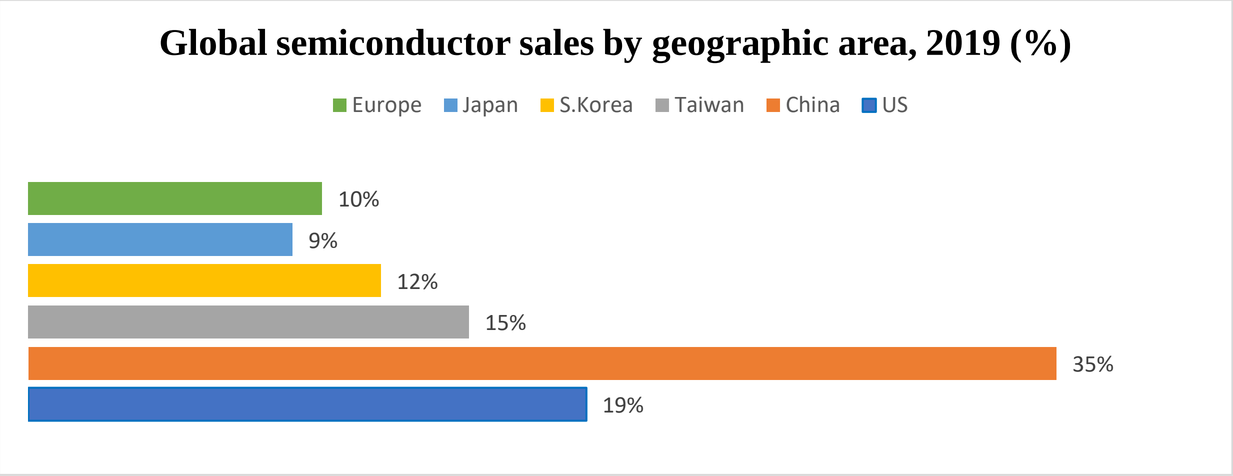

Figure 6.10: Global semiconductor sales by geographic area, 2019 (%) (Antonio Varas et Al, 2021).

China is the destination of approximately 35% of the shipments of semiconductors as many of the world's leading electronic device makers have their products assembled there—an activity further downstream in the electronics supply chain that is more labor intensive and with lower valued add.

The semiconductor industry is at the beginning of a complex supply chain leading to a large demand variability with a corresponding uncertainty of demand forecasts. Usually a manufacturer offers a variety of products, mainly in the areas communication, automotive and industrial, wireless solutions, chip card & security and memory products. To some extent, this highly distributed structure of the semiconductor supply chain follows the global geographic footprint of the electronics industry that the semiconductor industry serves.

Proximity to the leading firms that develop these devices may be important for semiconductor design companies. Different regions have strength in certain types of end electronics devices or applications:

- **US** is the global leader in the design of electronic devices. US consumer electronics, information technology, automotive and industrial firms source 35% of the semiconductors used in the world, with particular strength in advanced chips for PCs and data centers.

- **China** (including Taiwan) is the largest manufacturing global hub for electronic devices. Together, local original equipment manufacturers (OEMs) and contract manufacturers that assemble devices designed by other companies based elsewhere are responsible for more than 60% of the world's production of consumer electronics, smartphones, and PCs. Proximity to these companies that are the ultimate destination of the components to be assembled into devices may be important for semiconductor manufacturing companies.
- **Europe** is the global leader in automotive and industrial automation equipment; Japan is strong in these two sectors and also consumer electronics; South Korea is a global force in smartphones and other consumer electronics, too.

While we estimate that US-based electronic device makers are responsible for sourcing 33% of the total global semiconductor demand, in many cases their devices are actually manufactured outside the US. Less than 20% of total semiconductors sales are actually shipped to the US to be integrated into a product. Instead China is the destination of approximately 35% of the shipments of semiconductors as many of the world's leading electronic device makers have their products assembled there—an activity further downstream in the electronics supply chain that is more labor intensive and with lower valued add (Antonio Varas *et Al*, 2021).

Geographic specialization

In general, the semiconductor industry has multiple points of high geographical concentration across the current semiconductor value chain.

Six major regions have a significant participation in the total global output of the semiconductor industry:

1- *China*;
2- *Europe*;
3- *Japan*;
4- *South Korea*;
5- *Taiwan;*
6- *United States*.

But each region plays a different role in the global semiconductor supply chain, broadly speaking:

- The activities that are most intensive in R&D: EDA and core IP, chip design and manufacturing equipment, are mainly performed in US;
- Raw materials and manufacturing (both wafer fabrication as well as assembly, packaging and testing), which are more capital intensive, are largely concentrated in Asia.

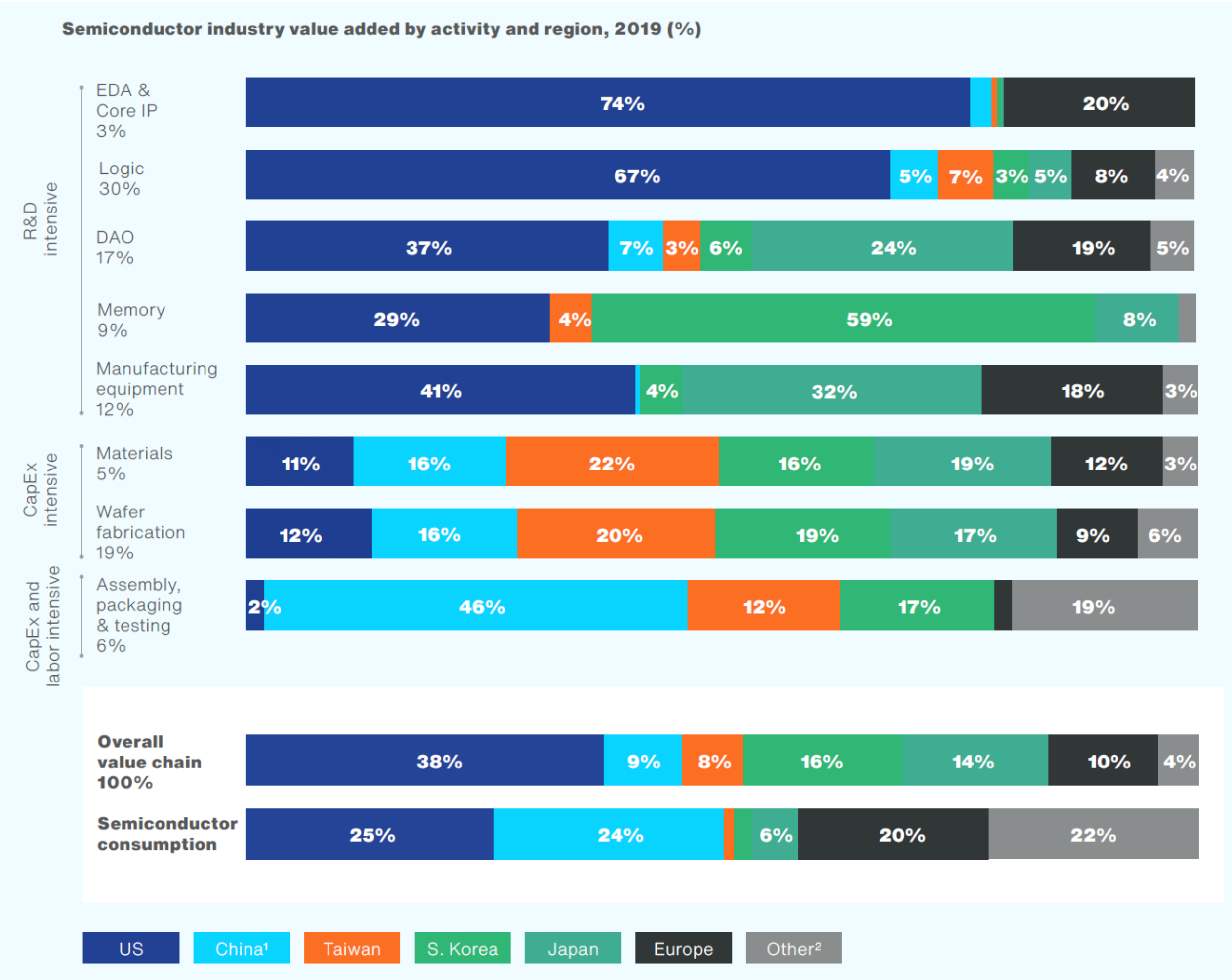

Figure 6.11: Semiconductor industry value added by activity and region (Antonio Varas *et Al*, 2021, p. 31).

6.2 Global supply chain model

Considering all the tier of the semiconductor supply chain, can be stated that is a global supply chain, because we are dealing with companies that are manufacturing or sourcing all around the world.

A global supply chain enables semiconductor companies to survive, thanks to:

- *Efficiency reasons:* outsourcing & offshoring reduce substantially man power, materials and machine costs. The manufacturing concentration and in general the global specialization are key factor in the industry enhancement over the last decades;
- *Effectiveness reasons:* having factories and supplier close to the final market.

Semiconductors are highly complex products to design and manufacture. The need for deep technical know-how and scale has resulted in a highly specialized global supply chain, in which regions perform different roles according to their comparative advantages.

Summarizing briefly all the tiers of the supply chain explained above, the US leads in the most R&D-intensive activities—EDA, core IP, chip design, and advanced manufacturing equipment—owing to its world-class universities, vast pool of engineering talent and market-driven innovation ecosystem. East Asia is at the forefront in wafer fabrication, which requires massive capital investments supported by government incentives as well as access to robust infrastructure and skilled workforce. China is a leader in assembly, packaging and testing, which is relatively less skill- and capital-intensive, and is investing aggressively to expand throughout the value chain. All countries are interdependent in this integrated global supply chain, relying on free trade to move materials, equipment, IP, and products around the world to the optimal location for performing each activity. In fact, semiconductors are the world's fourth-most-traded product after only crude oil, refined oil, and cars.

This global structure delivers enormous value.

Given these information, we can conclude that the main global supply chain model, for the main players (IDMs and foundries) in the semiconductor industry is *the ultra-high tech model (also called "octopus model")* (Henrique Luiz Corrêa, 2014, Page 70).

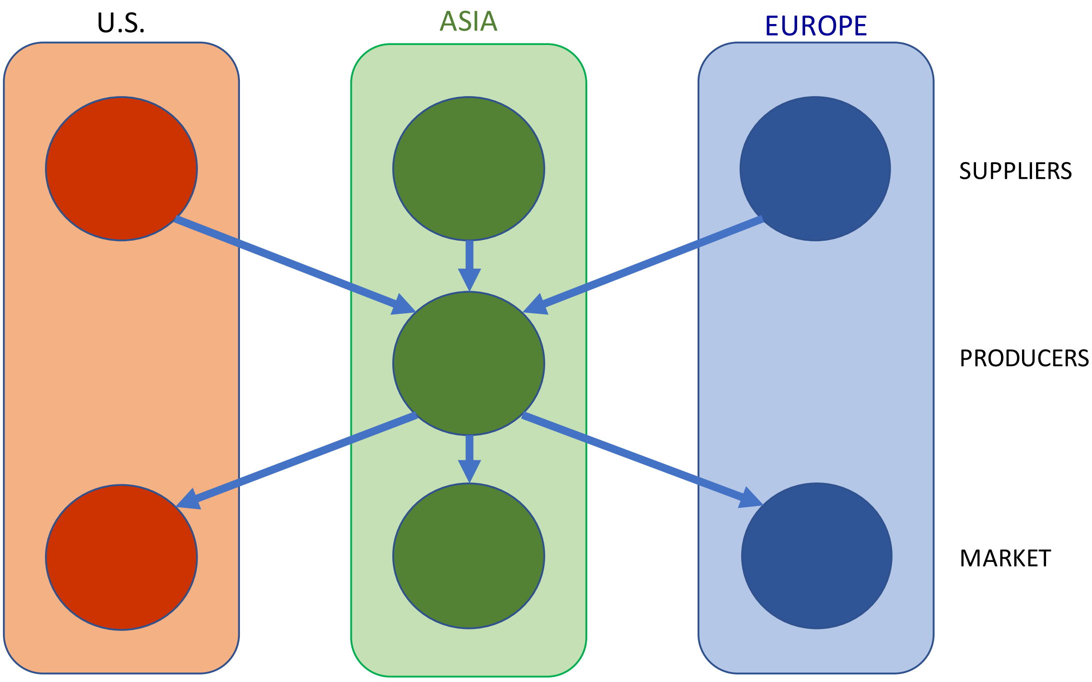

Figure 6.12: Global semiconductor supply chain model

Since the companies involved in this industry, are global brand with huge R&D investments paid back on a global scale only, that required a centralized manufacturing plant.

In addition, being part of international markets for sophisticated technologies, required a sourcing phase, that involves suppliers from many countries all over the world.

6.3 Supply chain strategy

Supply Chain has become a fundamental issue in the two-hundred-billion-dollar (plus) semiconductor industry, which provides building blocks for today's global information economy.

Semiconductor supply chain issues:

1- *Process characteristic: process variability*

The semiconductor industry is very much driven by cycle time. Considering the three semiconductor supply chain stages (front-end, back-end, and delivery) as three "black-box" processes. Process characteristics of each box are represented by a cycle time distribution.

An important process characteristic is capacity, that is often reserved based on demand forecasts. However, true capacity for a given semiconductor product is often unstable in real life. There are a lot of different products competing with each other for factory resources, while undesired events, such as reworks and unpredictable machine breakdowns, are not rare events in semiconductor factories.

2- *Process characteristic: process cost*

   Wafer fabrication is very costly. For example the 300mm raw wafer purchasing price is approximately $400 per wafer; this contributes about 12% to the $3200 front-end processing cost. Back-end process can cost as much as front-end. A 300mm wafer can generate about 400 such chips. Thus, total back-end cost per wafer is approximately $3200. Shipping costs for small semiconductor devices are neglectable.

   These costs vary considerably for different IC designs and process technologies. Such costs, in essence, contribute in a major way to the inventory holding costs (as capital opportunity costs).

3- *Demand characteristic: average demand quantity (demand vs capacity)*

   It is observed that the semiconductor industry is always under stress: in either a “lack for capacity” or a “lack for sales” situation. Meanwhile, demands of semiconductor products are well known to be highly uncertain.

4- *Demand characteristic: the lead time customers require*

   Customers may require a very short lead time or a very long lead time. Making a semiconductor integrated-circuit is an extremely complex process, and typically takes six to ten weeks.

5- *Demand characteristic: customers' perceived importance on service*

   On-time delivery has become the most important service issue in the semiconductor industry. Customers of different products often have different sensitivities to on-time delivery, with relative service penalties, which represent the customers' perceived importance of on-time delivery (Esma S. Gel *et Al*, 2010, Page 12).

6.3.1 Fisher analysis

Fisher provides a concise framework for identifying the right supply chain strategy for a given product. Traditionally, semiconductors are examples of innovative products with unpredictable demand and short product life cycles. Thus, a market-responsive supply chain, primarily a pull system, is suggested to be generally more appropriate than a physically efficient supply chain (primarily a push system).

However, this knowledge does not appear to be common in the boardrooms of semiconductor firms. The seeming protection of large WIP has not been easily overcome in this industry, even in firms purporting to adopt just-in-time philosophies. Most semiconductor manufacturers adopt primarily a push approach in order to maximize the utilization of their facilities that are under multi-million-dollar weekly depreciation and to eliminate or reduce the manufacturing cycle time seen by customers. In fact, most semiconductor devices are considered primarily functional today (all high-tech product markets eventually evolve into commodities). Thus, push in a major way remains as the de facto standard in this industry.

Demand uncertainty is linked to the predictability of the demand for the product. Innovative products are products that have short life cycles with high innovation which, as a result, have highly unpredictable demand. High-end computers and the latest integrated circuits are examples of innovative products. Demand for innovative products is highly unpredictable, these products tend to have higher product profit margins, but the cost of obsolescence is high (Hau L. Lee, 2002, Page 106).

Semiconductor industry has been experienced serious bullwhip effect in its supply chain over the years. Considering the variability exists in semiconductor supply chain:

1- *PRODUCT LIFE-CYCLE*
   Several months (less than 24 months). "The demand for semiconductor components is extremely volatile especially since it only has a life cycle of approximately 1.5 years". (Robert Miles, 2017, page 4)
2- *CONTRIBUTION MARGIN*
   Leading-edge technologies with high profit margins (around 30-40%);
3- *VARIETY*
   Huge product variety, due to the rapid introduction of new product options, constant technology advancements;
4- *AVG FORECAST ERROR*
   Forecast error, are generally wide spread in the industry, due to the high volatility of the demand, that do not allow precise forecast;
5- *INFLATING ORDER*
   Due to the long lead time and big spike in downstream demand, inflating order is common practice in this supply chain. the boom-bust cycle shows the difficulty in forecasting demand;
6- *AVG STOCKOUT RATE*
   High, due to difficulties related to the demand forecast, in downstream volatile market;

7- *END OF SEASON MARKDOWN*

Due to the high level of forecast errors, end of season markdown, are high for the industry, also due to the rapid obsolescence of the semiconductor ptoducts;

8- *LEADTIME FOR MTO PRODUCTS*

"The manufacturing lead time is quite long (at least 6/8 weeks), while cycle times: 7/8 weeks" (Lisa Forstner and Lars Mönch; 2013, Page 4).

(Hartmut Stadtler & Cristoph Kilger, 2004, Page 424)

The total lead time for the semiconductor supply chain is on average 20 weeks, even if these long lead-times, over half of the orders are fulfilled within 4 weeks. The demand for semiconductor components is extremely volatile especially since it only has a life cycle of approximately 1.5 years. The rapid drops in demand can leave companies with excessive inventory at the end of the product life, whereas the rapid rise in demand can lead to stock-outs and lost revenue as consumers turn to the competition (Robert Miles, 2017).

In addition, the rapid changing markets in the volatile semiconductor industry with its short development cycles complicates the forecasting process and typically leads to low forecasting reliability and obsolete, unsaleable inventory.

Planning is characterized by the product typology, in transparent processes caused by the varying requirements of the different product divisions. The product families differ in production processes (make-to-stock, make-to-order) as well as in lead times and cycle times, resulting in significantly varying planning horizons (from days to months).

Moreover, the capital-intensive machines, long production cycle times, volatile demand, continuous cost and price pressure, high degree of product variants, fast changing up- and downturns as well as short product life cycles are typical for this industry (Lars Mönch *et Al*, 2013).

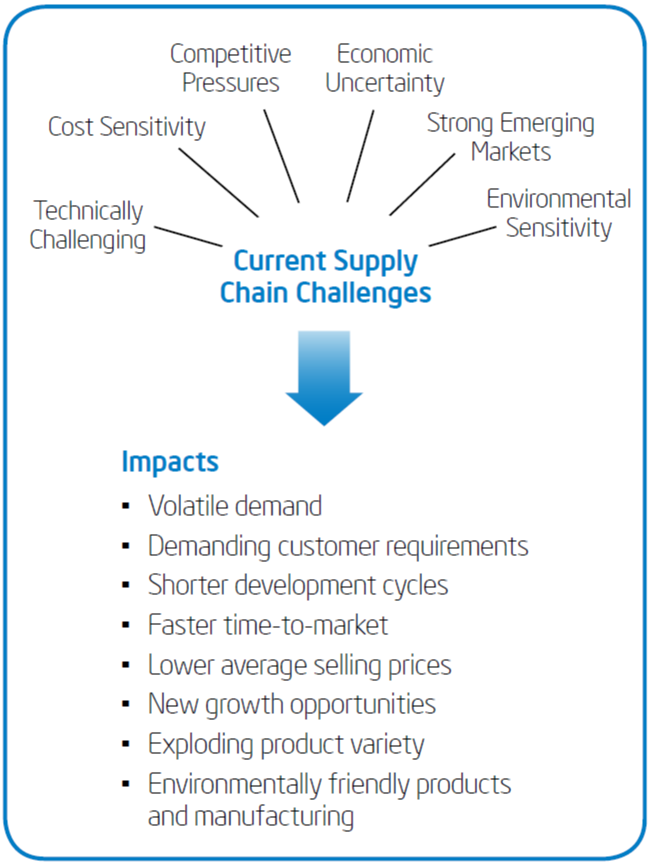

Figure 6.13: Market pressures require an efficient and agile supply chain (Russ Hensley *et Al*, 2012, page 3).

To deal with this dynamic environment, semiconductor companies have to react quickly on the changing needs of the customers regarding product type and quantity, but at the same time, they also seek to keep costs as low as possible. Low inventory levels might lead to a poor delivery performance, whereas keeping inventory levels high increases the risk of obsolescence and leads to higher capital commitments.

There are also many industry- and market-driven supply chain challenges. Expanding product offerings and shrinking product life cycles, new and shifting market conditions, emerging regulations, and more demanding customer expectations

require that semiconductor supply chains continue to improve on existing supply chain processes while being able to quickly adapt to new supply chain business requirements and create solutions to support them.

Supply chain capabilities are critical to meeting market demands. These demands include the following:

- Increased product mixes and volume;
- Shorter delivery times;
- Increased responsiveness to change requests;
- More efficient and cost-effective performance;
- Increased competition as new products are introduced;
- Increased environmental sustainability;
- Changing government regulations.

(Russ Hensley *et Al*, 2012)

6.3.2 Hau Lee analysis

Lee adds the nature of the process to that of the product in Fisher's framework. Semiconductors are known to have not only highly uncertain product demands but also highly unstable production processes. Thus, Lee's framework recommends a postponement strategy (in essence a push-pull approach) for running the complex semiconductor supply network. Lee discusses the development and implementation issues of a die-bank-based push-pull system, moving from a traditional pure push strategy to a push-pull strategy can help the firm improve financial performance by holding less finished goods, yet still be responsive to customers.

Supply chain management is about matching supply with demand. The supply chain strategy needs to be appropriately determined not only for the given product, but also for the given supply process. Hau Lee classifies the characteristics according to the Process Stability/Instability and the demand variability.

Other kinds of uncertainties revolving around the supply side of the product are equally important drivers for the right supply chain strategy.

- *Demand variability;*
- *Process stability (supply & production side).*

An "evolving" supply process is where the manufacturing process and the underlying technology are still under development and are rapidly changing, and as a result the supply base may be limited in both size and experience. In an evolving supply process, the manufacturing process requires a lot of finetuning and is often subject to breakdowns and uncertain yields. The supply base may not be as reliable, as the suppliers themselves are going through process innovations.

Process stability

- *Complex manufacturing process*

  "The semiconductor industry has one of the longest and most complex manufacturing processes and supply chains. The production of a single computer chip often requires more than 1,000 steps passing through international borders 70 or more times before reaching an end customer" (Saif M. Khan *et Al*, 2021, Page 5);
- *Geographical concentration:*

  "While geographic specialization has served the industry well, it also creates vulnerabilities that each region needs to assess in a manner specific to its own economic and security considerations. There are more than 50 points across the supply chain where one region holds more than 65% of the global market share. While geographic specialization has served the industry well, it also creates vulnerabilities that each region needs to assess in a manner specific to its own economic and security considerations. There are more than 50 points across the supply chain where one region holds more than 65% of the global market share" (Erik Pederson *et Al*, 2020, page 5);
- *Geopolitical tensions for trade*

  "Geopolitical tensions may result in export controls that impair access to critical providers of essential technology, tools, and products that are clustered in certain countries. Such controls could also restrict access to important end markets, potentially resulting in a significant loss of scale and compromising the industry's ability to sustain the current levels of R&D and capital intensity" (Erik Pederson *et Al*, 2020, page 6);

AGILE supply chain

The pandemic and the chip shortage have made one thing abundantly clear: a flexible, agile supply chain is crucial to navigating the changes and staying resilient.

These are supply chains that utilize strategies aimed at being responsive and flexible to customer needs, while the risks of supply shortages or disruptions are hedged by pooling inventory or other capacity resources. These supply chains essentially have strategies in place that combine the strengths of "hedged" and "responsive" supply chains. They are agile because they have the capability to be responsive to the changing, diverse, and unpredictable demands of customers on the front end, while minimizing the back-end risks of supply disruptions.

The semiconductor industry involves innovative products with evolving supply processes companies with innovative products and evolving and unstable supply processes have to utilize the combination of risk-hedging and responsive strategies.

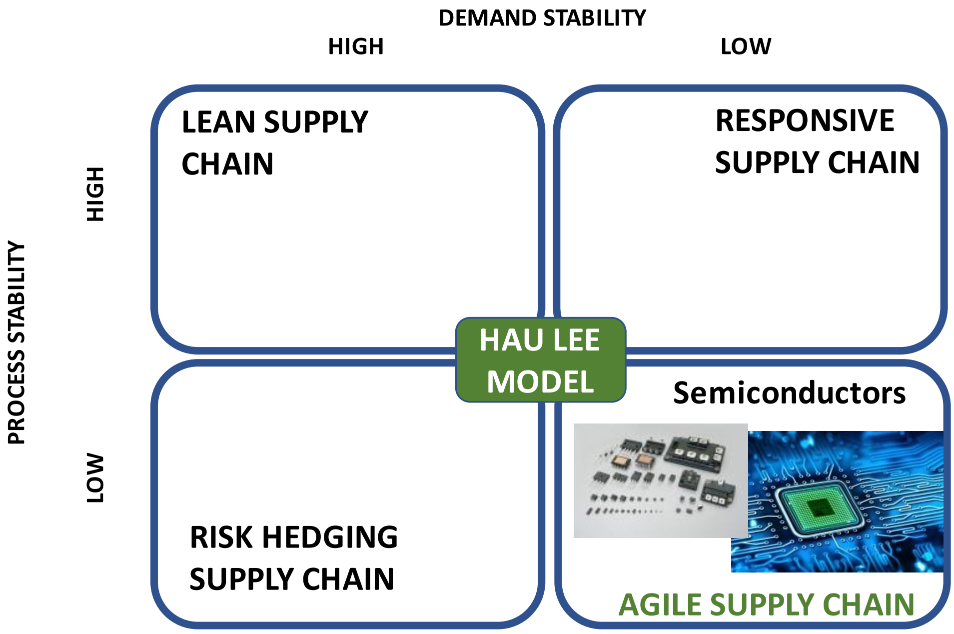

Figure 6.14: Lee's matrix (Hau L. Lee, 2002, page 117).

The appropriate strategy here, is to establish "agile" supply chains. Market players in semiconductor industry, have to deal with the market uncertainties in both supply and demand. These uncertainties have aimed at creating agile supply chains.

Demand and supply uncertainties can be used as a framework to devise the right supply chain strategy. Innovative products with unpredictable demand and an evolving supply process as semiconductor products face a major challenge. Because of shorter and shorter product life cycles, the pressure for dynamically adjusting and adapting a company's supply chain strategy is mounting. Using the Internet to develop agile supply chains with information sharing, coordination, and postponement has enabled companies such as Xilinx to compete successfully in their market places. The challenges are great, but so are the opportunities (Bindiya Vakil and Tom Linton, 2021).

6.4 Fabless-foundry supply chain

The fabless-foundry supply chain, as shown in the exhibit below #, is fragmented, since many steps are outsourced, in order to let concentrate fabless companies to their core activity, the design phase.

In today's semiconductor industry the value chain is dynamic and managed via partnership between all the value chain creators. Fabless semiconductor company's value chain is described in the following block diagram. It assumes that the Fabless semiconductor company has agreements with all the typical suppliers such as: EDA companies, Wafer supplier and OSAT companies.

Being more flexible than IDM's supply chain, brings many advantages to fabless companies, but on the other hand, fabless' s supply chains have to cope with leading-edge technologies that have unstable supply processes and demand.

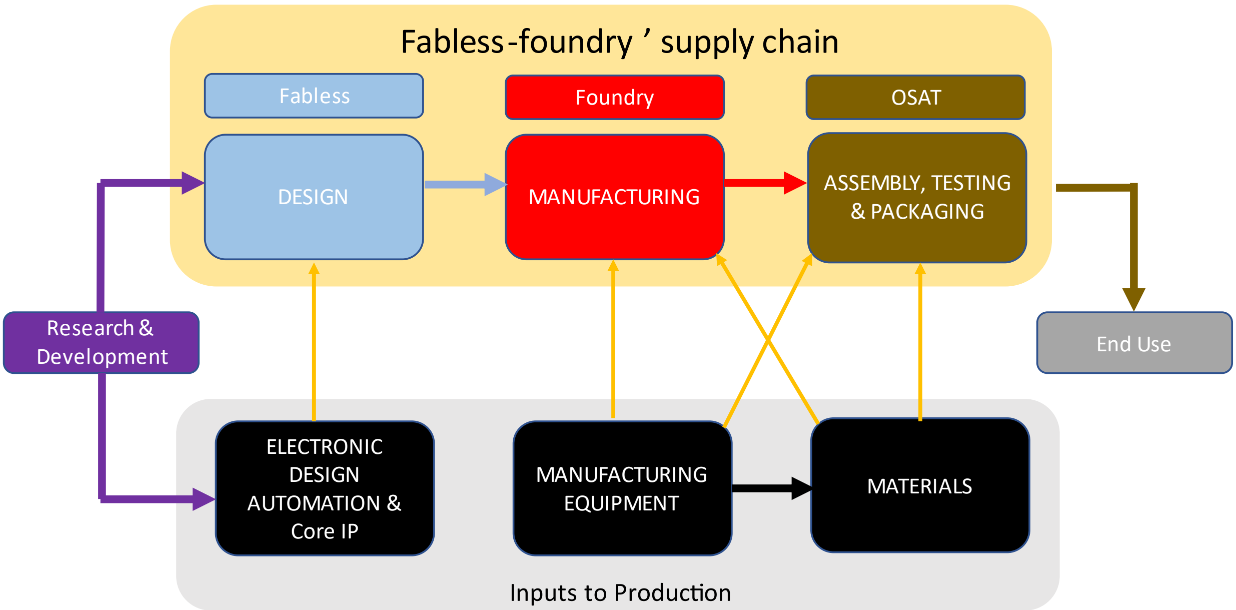

Figure 6.15: Fabless-foundry supply chain

Most semiconductor fabless companies are stuck between a rock-and-a-hard-place. On one end, they have big customers, with high bargaining power; and on the other end, they have big suppliers manufacturing their products—some 16 time zones away. Synchronizing and managing capacities and deliveries through a complex supply chain like this cannot be easy. Compounding the complexity is the short life-cycle of such products and the long manufacturing lead-times through outsourced Fabs. With every new product, you basically have to revamp a good part of your supply chain, quickly. The common theme to all of these challenges is time and uncertainty.

Manufacturing involves a Planning cycle-time and a Manufacturing cycle-time. Fabless companies don't control the manufacturing lead-time since all of their production is outsourced. However, they do have the opportunity to manage the suppliers' capacity that is committed to them—which becomes part of the Planning cycle-time. They also have to worry about the uncertainty of what they will order with the amount of capacity that they have been promised. This makes the Planning cycle-time, and accuracy of the plan, twice as important to a fabless enterprise.

Planning cycle time is the amount of time a company needs to plan, react, and/or roll out a new plan based on market demand, inventory positions, and supplier capacity commitments. Its reduction translates to less uncertainty and increased accuracy. To that end, reducing planning cycle-times is a colossal competitive factor in this market.

Xilinx case:

Xilinx Inc., a fabless semiconductor company specializing in high-end integrated circuits, relies on such a strategy to compete successfully in the market place. "High-end semiconductor chips are highly innovative products, often representing the first generation of the most powerful integrated circuits. Since they are pushing the frontier, the process technology used and process control methods required for the wafer fabrication process are very demanding and challenging" (Hau L. Lee, 2002, p. 117).

Xilinx has formed very tight partnerships with two such foundries. United Microelectronics Corporation in Taiwan and Seiko in Japan. Fabricated wafers are then stocked, forming a decoupling point known as die banks. As demand for specific chips is known through orders from consumer telecommunication and automotive industries, the final assembly and testing of the chips are carried out by other supply chain partners in Korea, China and the Philippines. Such a decoupling point strategy enables Xilinx to be responsive to the diverse and changing needs of their customers, who themselves are faced with highly unpredictable demand for their end products.

Xilinx products are field-programmable, i.e., some of the functionalities of their chips can be specified by software in the field, even after they have been delivered to the customer. In this age of rapid technological developments, some of the products in which Xilinx chips reside are going through constant product generation changes that would require the updating of the functionalities of the Xilinx chips. The field-programming logic can be modified or updated after the installation at the end user's premises over networks and the Internet, giving flexibility to the whole supply chain (Hau L. Lee, 2002).

6.5 IDM’s supply chain (Intel case)

As shown in the figure 6.16, an IDM’s supply chain embrace all the phases of a semiconductor supply chain, from the design to the assembly, testing & packaging passing through the most complex step, the manufacturing process. Due to the high vertical integration, adopted by these companies, the IDM supply network is a multi-tiered supply chain with multiple layers controlled by the same organization.

Contrary to the fabless’ s supply chain, IDMs are more focused on costs and performances of their supply chains, since their main product technologies are well established, so the demand and supply process are more stable.

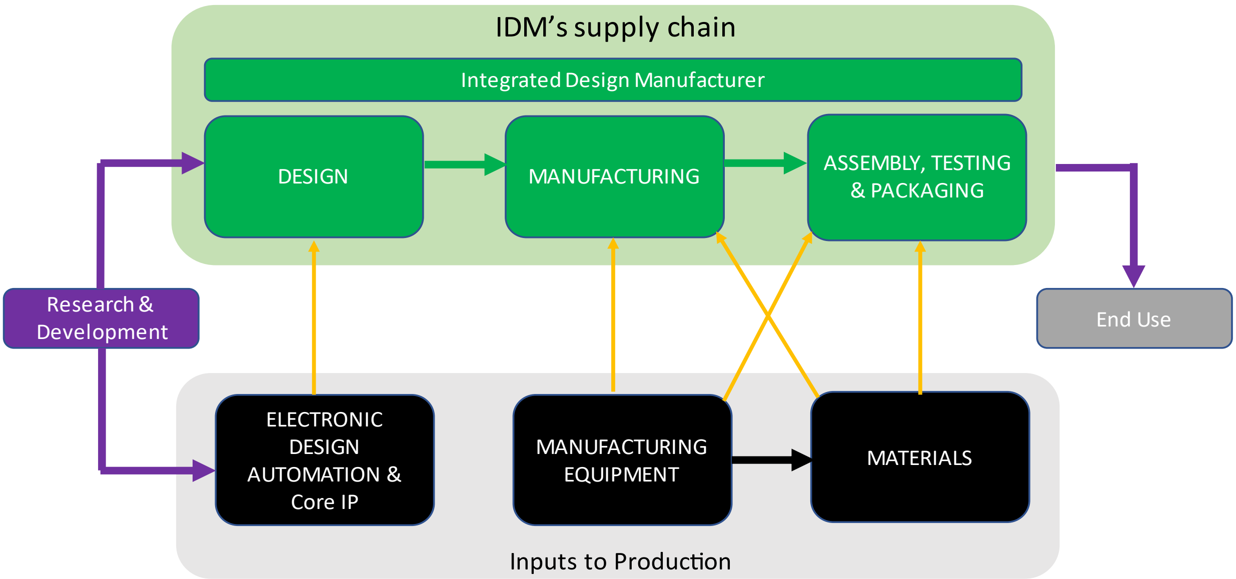

Figure 6.16: IDM’ supply chain

For instance, the Intel’ supply chain is comprised of more than 19,000 suppliers in over 100 countries. These suppliers provide everything from direct production materials to the tools and machines required in assembly and manufacturing. There are also suppliers of logistics, packaging, office materials and even travel services. (Robert Miles, 2017)

The first tier of the supply chain is that of mining and manufacturing the bare silicon wafers. The manufacturing stage consists of hundreds of different steps and takes an average of 10 weeks as the wafers are divided into integrated circuits. Once the integrated circuits are manufactured, they are then sent to an E-test and Sort which determines if each integrated circuit functions as intended. After this sorting, all the circuits are inventoried as work-in-progress and then sent to the Assembly/Test phase. Here the integrated circuits are separated into their individual chips and packaged. Once packaged, the chips are then inventory warehoused until they are shipped to the customers. This process, from E-test to shipping to customers takes an additional 10 weeks on average. Although the entire supply chain takes approximately 20 weeks, more than 50% of Intel's orders are met within 4 weeks due to an incredible forecasting and inventory management process.

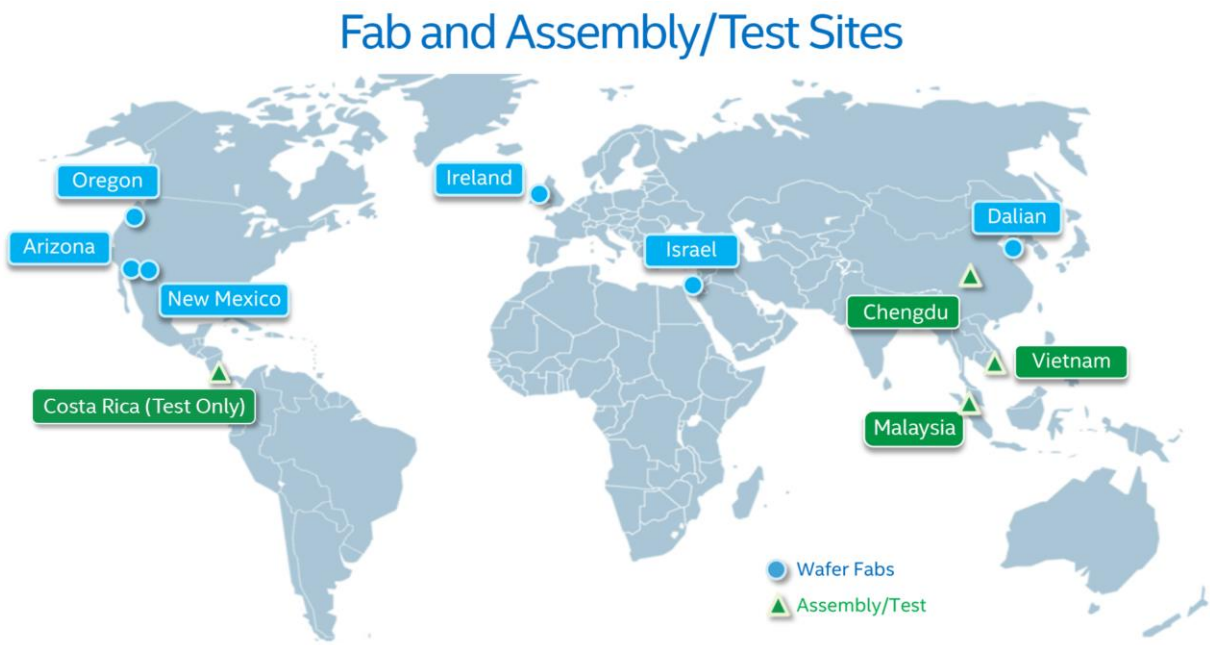

Figure 6.17: Intel worldwide manufacturing network (Russ Hensley *et Al*, 2012, Page 2).

In general, manufacturing technology and operations are at the center of IDM's business. IDM factories turn raw silicon wafers into complex and advanced integrated circuits. The manufacturing process produces integrated circuits that are delivered to customers as finished goods or subsequently used in the assembly of products such as CPUs, graphics processing units (GPUs), memory units, communication controllers, motherboards, wireless devices, and solid-state drives (SDDs).

The importance of the supply chain in Intel's continued manufacturing leadership and business growth has steadily increased over the last decade. Intel's primary supply chain for wafer manufacturing is complex, as each integrated circuit or die goes through hundreds of steps as the product and materials move from the planning stage through production, packaging, warehousing, and delivery to customers. In addition, Intel is currently manufacturing multiple generations of process technology in high volume in its manufacturing network of 16 factories—11 fabrication facilities and five assembly/test factories spread across seven countries, as explained in figure 6.17. Approximately 30 global warehouses handle the warehousing and delivery to customers of these products, shipping about 1 million PC units per day and fulfilling over 750,000 orders per year.

Moreover to integrated circuits, Intel also maintains a diverse set of products, such as wireless controllers, software products, and SSDs, serving many different markets. The resulting complexity drives multiple supply chain requirements and capabilities that differ from the core wafer manufacturing supply chain. Each of these additional supply chains requires planning, forecasting, inventory management, packaging, and shipping.

To support an efficient and responsive supply chain, Intel IT works closely with many teams throughout Intel to formulate a strategy that integrates IT solutions across all levels. While manufacturing technology and operations are at the center of Intel's business, Intel recognizes that supply chain capabilities are critical to meeting market demands.

Intel IT helps Intel's supply chain meet these demands by partnering with the internal business teams to re-engineer business processes and deliver more efficient information systems. These systems are associated with multiple aspects of supply chain management, including planning, demand forecasting, production planning, order fulfillment, warehousing, and logistics.

Through several initiatives in the last few years, including standardizing Intel's enterprise resource planning (ERP) platform, developing automation and business intelligence solutions, and simplifying supply chain planning processes, Intel IT has helped to increase supply chain responsiveness and productivity while reducing process cycle time and inventory levels (Russ Hensley *et Al*, 2012).

6.6 Supply Chain Evolution

The transformation continue as semiconductor companies will implement additional IT-enabled solutions to support changes in market conditions. Emerging supply chain challenges include the following:

- A continually increasing portfolio of products and services, such as tablets, smart phones, and embedded technologies;
- Issues related to the global supply chain, including government regulations, available infrastructure, worker location, environmental sustainability, and social media;
- Emerging markets and expanding customer reach.

To address these challenges, supply chain managers are looking to implement agile and adaptable IT solutions that can be used across multiple supply chains. Clear identification and definition of business requirements for the various supply chains, including service levels and supply chain models, will allow companies to more effectively deliver robust solutions that can be quickly changed to support market conditions and customer requirements. For example, while continuing the make-to-stock (push) model for traditional CPU products, many companies are implementing pull and hybrid models to support some new product market segments.

- In a push model, the supply chain is run based on the demand forecast for finished goods, and inventory is managed to support the forecasted demand. Semiconductor companies forecast and push the inventory to the warehouse and hub locations that seem best positioned to support customers.
- In a pull model, products are finished once the customer actually places the order.
- In a hybrid model, certain portions of the supply chain use a push model to stage inventory (either finished goods or components) and then the final products are created based on the pull model.

Pull models offer several primary potential benefits:

- Increased responsiveness;
- Reduced inventory and product obsolescence in new and changing markets that require higher SKU counts;
- Varying levels of customer responsiveness.

In the future, the goal for semiconductor supply chains, to have the ability to dynamically select the right push, pull, or hybrid model based on product type and product life cycle.

6.6.1 Supply chain conclusion

Supply chain performance is measured as a combination of production costs, inventory costs, and service related costs. The semiconductor manufacturing industry is highly capital intensive and is characterized by high customer expectations, short product life cycles, proliferating product varieties, unpredictable demands, long and variable manufacturing cycle times, globally distributed logistics, and considerable supply chain complexities. However, this industry has been driven by technological innovations rather than supply chain efficiency since its birth, while the dilemma executives face today is that markets have become more competitive when the semiconductor industry itself has become more commoditized.

Meanwhile, having the most advanced chip is not the only key to competition. In general, manufacturers must also compete on cost, quality, and efficiency to deliver a good customer seervice. The firm's supply chain-wide performance therefore must be managed in the following two dimensions: increased customer service and reduced cost. Today's semiconductor customers are insisting on better service, especially on-time delivery. While the specifications (function, quality, price, etc.) of the commoditized semiconductor products are set by the market, cost and service are the key competitive issues. Cost and service are the major concerns for determining the supply chain strategy.

7 CONCLUSIONS

7.1 How are semiconductor manufacturers business model organized?

To conclude, the main two business models in the industry are IDM and Fabless-foundry model. The main differences between the two models, are the level of integration and the products produced (being the Fabless-foundry more oriented to high level of innovation).

From the business models analysis, emerges that to be profitable, semiconductor companies have to focus on product design and engineering. Indeed, today there is a clear trend towards business models convergence between companies in the industry. The costs for the fundamental development are increasing exponentially as the companies are trying to focus on this process, trying to reach advantages, through economies of scale. Indeed, economy of scale is getting crucial to be competitive and this is the most significant driving factor for the outsourcing processes (regarding the production phases), performed by many IDMs to survive.

The fast rising costs are leading to a repositioning of the Integrated Device Manufacturers, many of them are realizing that they do not have the quantities necessary for driving fabs and manufacture in-house. This has resulted in that many IDMs are selling fabs and outsourcing large parts of their manufacturing to foundries. Without the foundry part, Integrated Device Manufacturers (fabs) have a more narrow area of business and are compensating this by scaling the value chain, trying to establish as technology enablers.

The value in hardware is no longer dominating; there are massive amounts of money in intellectual property rights and software, something that the Integrated Device Manufacturers have realized and are trying to capitalize on.

7.2 How are they implementing their business models into supply chains?

There are several differences between a IDM' supply chain and a Fabless-foundry' supply chain. The main reasons behind, are due to the structure and product differences.

The main distinction, is the level of integration, that bring to multi-tiered supply chain with multiple layers controlled by the same organization, for the IDMs, while fabless' supply chains have less layers under control of the same company. Secondly, the product families differ in production processes (make-to-stock, make-to-order) as well as in lead times and cycle times, resulting in significantly varying planning horizons (from days to months). Following the Fisher and Hau Lee analysis, we can state that IDM and fabless companies face both unstable demands and unstable processes, but fabless companies in a more critical way, for the nature of their products (more innovative). As seen before, IDM companies rely more on products which are largely general-purpose components and more scalable, that obviously have more stable processes.

On the other hand, the complexity of the IDM's structure enhances tremendously the supply chain' complexity, since many phases have to be performed internally, as the manufacturing process.

So the IDM's supply chain integrate also the manufacturing and the assembly, testing & packaging phase, in addition to the design phase.

In both cases, an "Agile" supply chain strategy is needed, in order to cope with the market and supply uncertainties, but the specific supply chain' actions put in place can vary a lot, due to their different business models, bringing the fabless-foundry supply chain to be the extremization of the concept of "agile" supply chain, while the IDM's supply chain is more related to a "Responsive" supply chain.

7.3 Contribution to the theory and to the practice

Since the concept that, IDM model is starting to be obsolete, has been consolidated for years, the main contribution to the theory and to the practice of this paper, is related to following step of the business model developing path. Indeed, a clear concept emerges from the analysis, there is the need to expand even further the Foundry model, becoming even more a network of enterprises.

A growing volume of customers have diverse product and program needs as they push to create unique end products. This trend will only gain steam as 5G becomes more pervasive, enabling companies to capitalize on applications that weren't possible with previous generations of networks. That means semiconductor companies must spread their product design and engineering capabilities across many different industries, customers, and products.

Bring this all together and suddenly semiconductor companies find themselves trying to serve more customers and more unique needs with an internal infrastructure built to design products to service a specific market while trying to differentiate themselves and deal with customers that have differing breadth and depth.

Actually, product design and engineering is a semiconductor company's core competency and primary differentiator. And the suggestion of this paper is to establish an organizational structure that allows these businesses to do what they do best, focusing on their core competencies. As TSMC is doing, started the movement to outsource chip manufacturing, which freed themselves to focus on design and engineering infrastructure. Now market dynamics are adding further pressure on that engineering infrastructure. Chip companies need to move up the engineering experience to create a similar foundry model for infrastructure and operational engineering, enabling them to get much closer to customers.

As markets evolve and diversify, pulling in outside organizations to handle infrastructure drives scale and creates the ability for infrastructure roles to support and grow in a flexible way across different design cycles, customer requirements, and market opportunities. By partnering with another organization, companies can attack new businesses and industries with new chip designs, and gain perspective on whether new alliances are successful without having to ramp up the in-house capabilities. In this way, the organization retains its key talent and has the flexibility to adapt infrastructure with a rapidly changing market. It's a scalable, agile approach that de-risks the business and saves cost.

Scalable and flexible structures allow semiconductor companies to divest themselves of inflexible and costly infrastructure and operational capabilities, there is the need of scalable and flexible organization.

The best starting point is to assess which parts of your engineering capabilities are fungible, meaning those that require industry skills but not product-specific skills. If you can separate fungible skills from product-specific skills, those fungible skills are candidates for co-engineering partnership. If they're repeatable skills, they may also be candidates for automation and AI by either your company or your third-party partner.

As the market for semiconductors becomes more complex and diverse, companies that can effectively contract for infrastructure and operational engineering will free themselves to focus on their customers and product designs, meeting a much broader range of needs and applications. And, with partnered capabilities behind them, they will have the flexibility, scale, and cost base to move with the market—continuing to design the chips to power a growing range of innovative high-tech products.

7.4 Limitations and suggestion for future research

7.4.1 Limited number of semiconductor company's examples:

We have taken only 1 company for each business model typology; To be able to analyze how the semiconductor industry interfaces its business models with the ways in which are organized their supply chain, it is vital to study the overall industry and some of the main companies in detail, to see how they will develop. To make this an achievable assignment given the timeframe, there had to be some priorities made. Within the given timeframe it is not possible to study all the companies in the semiconductor industry. Consequently the study have limited the semiconductor companies to three of the most important companies in semiconductor industry, one for each business model in the industry:

- Intel;
- Xilinx;
- TSMC.

7.4.2 Secondary sources limitations:

7.4.2.1 Loss of control

The attractive easy features of secondary data carry with them a penalty though, in that the researcher is unable to exercise any control over their generation. And the fact that the researcher has not been involved in the gathering of the data means that effort needs to be expended in understanding the nature of the data and how they have been assembled. As in this work, have used secondary data, there is a danger that the researcher will misuse the data, perhaps drawing unwarranted conclusions (Christopher J. Cowton 1998).

In addition to seeking to understand the nature of the data being used, the researcher may also need to expend effort in processing them into a form suitable for his or her own purposes. For example, in the case of one of my own projects, which relies on the relationship between business models and supply chains, I spent a lot of time in data evaluation, in order to avoid the loss of control problem.

7.4.2.2 Theory and data

Another limitation of this work, is that notwithstanding the researcher's attempts to manipulate the data into a suitable form, having been generated for another purpose they are likely to address less adequately than desired the theoretical concerns of the researcher.

So, secondary data are likely to map only approximately onto the thesis ideal research questions.

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