Study on internationalisation and fragmentation of value chains and security of supply

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Case study on Semiconductors

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Author:

DECISION Etudes & Conseil

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This report has been prepared in 2011 for the European Commission, DG Enterprise and Industry under the Framework Contract of Sectoral Competitiveness Studies ENTR/06/054.

Abstract: The overall objective of the study is to analyse the degree and consequences arising from the internationalisation, fragmentation and security of supply of value chains for European industry. The focus is predominantly on the supply side (i.e. upstream) as opposed to the demand, downstream, side. While globalisation can indeed be a positive development for Europe, there are also risks involved.

Key subjects: Value chains, supply chain management, risk mitigation, industrial policy, competitiveness, globalisation, EU, aeronautics, electric vehicles, mobile devices, semiconductors, space…

Publisher: European Commission, DG Enterprise and Industry

Project leader: Jeremy Millard, Danish Technological Institute
Email: jeremy.millard@teknologisk.dk, phone: (+45) 72 20 14 17
Kongsvang Alle 29, 8000 Århus C, Denmark,

Performing organisations: Danish Technological Institute (Peter Bjørn Larsen, Jeremy Millard, Kristian Pedersen, Benita Kidmose Rytz) with Ecorys (Jan Maarten de Vet, Marc Vodovar (DECISION), Paul Wymenga) and Cambridge Econometrics (Graham Hay, Jon Stenning)

Author of the Semiconductor Case : Marc Vodovar (DECISION)

Framework contractor:
ECORYS SCS Group
P.O. Box 4175
3006 AD Rotterdam
Watermanweg 44
3067 GG Rotterdam
The Netherlands
T +31 (0)10 453 88 16
F +31 (0)10 453 07 68
E fwc-scs@ecorys.com
W www.ecorys.com
Registration no. 24316726

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1 Case study Semiconductors

1.1 Introduction

Critical factors in the semiconductor-high tech equipment value chain are clearly concentrated in the semiconductor (SC) supply chain part for several reasons:

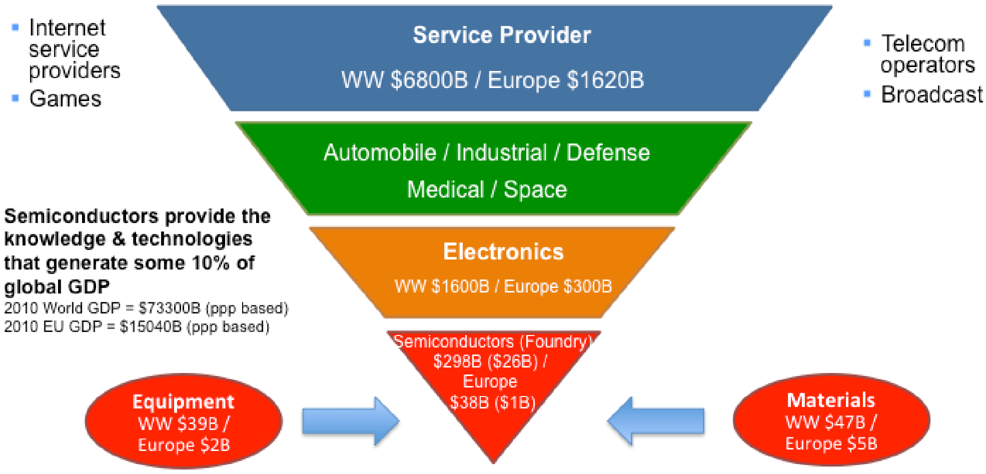
- The contribution of semiconductor technology to the global product added value is increasing;
- The semiconductor industry is the most capital-intensive in the world (with R&D representing 20% of revenues according to ESIA – Figure 4.4) and is exposed to several risks upstream and downstream;
- Access to electronic components is a major issue for the whole European industry and any significant disruption in the semiconductor value chain might have a large impact.

Semiconductor content in equipment is growing as intelligence is embedded in modern devices and appliances. It has grown from 2% in the 1960s to 20% in the 2000s and is expected to reach 20-25% in the 2010s. The pervasive use of semiconductors across many economic sectors has been, and will continue to be, the main driver of SC market growth. The driving force of the industry is changing over time: today semiconductor technology contributes to individual productivity through mobile devices and multimedia. The next wave of applications is likely to be societal needs like health, energy, transport and security, which by 2013 could represent 10% of the total market.

While the semiconductor sector can be described, classically, as the set of activities (or companies) that contribute to the design, production, packaging and commercialization of semiconductor devices, it is more useful to characterize the sector by a set of features, which today make it unique:

- Semiconductor's role as technology enabler for the whole electronics value chain. The sector has become a key driver for worldwide economic growth: with semiconductor production worth B€225 (B$ 298) in 2010, the industry enables markets worth B€1,200 (B$1,600) for electronics systems and B€ 5,130 (B$ 6800) for services (as shown in Figure 1.1).

Figure 1.1 Economic leverage of semiconductor value chain



Source: DECISION/ESIA/IMF/WSTS, 2011

- A long-term high growth trend (9% over the last 20 years) together with high volatility that leads to dramatic cyclical swings as shown by WSTS statistics;
- Fierce competition driven by constant, "never-ending" price decreases, itself driven by the rapid pace of change in the market, which in turn drives a staggering price-performance improvement rate.

The semiconductor value chain is highly fragmented and internationalized. It has "evolved from a linear chain to a networked model" (ESIA 2008) as "the growing complexity of nano-electronics technology and electronic products and services in general has strongly affected the landscape of the high-tech industry. Increasing complexity results in exponential increases in capital spending and critical know-how. In the early days of semiconductors, Integrated Device Manufacturers (IDMs) could handle the entire value chain, sometimes even extending their business into manufacturing equipment and materials at one end and electronic products and services at the other. Due to extensive de-verticalisation in the industry, that model has now changed. Many successful 'fabless' (fabrication-less) companies (semiconductor companies relying totally on third-party foundries)[1] have emerged. For cost reasons, many IDMs have also entered into industrial alliances in order to jointly develop common processes." (ENIAC SRA 2007)

The whole value chain is very complex but can be roughly broken down into four major steps:

1 ***Raw wafers production:*** a raw wafer is a thin slice of semiconductor material, such as a silicon crystal, that serves as the substrate for micro-electronic devices built in and over it. Wafers are formed of highly pure (99.9999% purity) single crystalline material. Its fabrication involves many complex steps and the use of several types of raw materials and chemicals The steps involved in the process are:
   1.1 Obtaining the sand: any sand (for instance from beaches) is suitable
   1.2 Preparing the silicon bath: the sand ($SiO2$) is put into a crucible and is heated to about 1600° C – just above its melting point. The molten sand will become the source of the silicon that will be the wafer.

[1] A semiconductor foundry is a company, which operates semiconductor fabrication plants producing integrated circuits (ICs) for other companies - for manufacturing.

1.3 Making the ingot: a pure silicon seed crystal is now placed into the molten sand bath. This crystal will be pulled out slowly as it is rotated. The result is a pure silicon cylinder that is called an ingot. The temperature and the rate at which the ingot is withdrawn determine its diameter. When it has the correct length, it is removed and ground to a uniform external surface and diameter.

1.4 Preparation of wafers: after the ingot is ground into the correct diameter for the wafers, the silicon ingot is sliced into very thin wafers. This is usually done with a diamond saw. Lapping removes the surface silicon, which has been cracked or otherwise damaged by the slicing process, and assures a flat surface. Wafers are then etched in a chemically active reagent to remove any crystal damage. A chemical/mechanical process polishes them in order to smooth out any remaining surface irregularities, and to make the wafer flat and smooth enough to support optical photolithography. The wafers then undergo a final test, performed in order to demonstrate conformance with customer specifications for flatness, thickness, resistivity and type.

2 ***Front-end processing:*** is the sequence of operations that lead, according to the design instructions, from the wafer to the small piece of silicon (die), which, once packaged, will become an integrated circuit. Most modern complex chips require over 300 processing steps including doping or ion implantation, etching, deposition of various materials, and photolithographic patterning. The basic steps are, in a sterile environment:

2.1 Diffusion: a layer of material such as oxide is grown or deposited onto the wafer.

2.2 Coat / bake. The resist, a light sensitive protective layer, is applied and cured in situ.

2.3 Align: a reticule is positioned over the wafer. Ultraviolet light shines through the clear portions of the reticule exposing the pattern onto the photosensitive resist.

2.4 Develop: the resist is developed and unwanted resist is washed away.

2.5 Dry etch: dry etch removes oxide not protected by the resist.

2.6 Wet etch and clean: the remaining resist is removed in wet etch to reveal the patterned oxide layer. Then the processed wafer is cleaned. The process is repeated up to 18 times to create the various layers necessary for each part's circuitry.

3 ***Back-end operations*** traditionally include assembly, the final step of semiconductor device fabrication, and testing of the resulting ‘chip’. These operations have long been considered as the less glamorous part of the process and were offshored and outsourced earlier than other parts. However, they are regaining favour as an important part of ‘more than Moore’[2] developments (multiple dies in one package). The major steps are:

3.1 Die attach / wire bond: before the die are encapsulated, they are mounted onto lead frames, and thin gold wires connect the bonding pads on the chip to the frames to create the electrical path between the die and lead fingers. Product

[2] “Moore” refers to the “Moore’s law” which says that states: “The number of transistors that can be placed inexpensively on an integrated circuit doubles approximately every two years”. As the rhythm seems to slow down with physical and economic constraints, other ways are explored to continue fast integration of new functions. The "More than Moore" approach typically allows for the non-digital functionalities (e.g. RF communication, power control, passive components, sensors, actuators) to migrate from the system board- level into a particular package-level (SiP) or chip-level (SoC) potential solution.

samples are taken out of the normal product flow for environmental and reliability assurance testing.

3.2 Encapsulation: lead frames are placed onto mould plates and heated. Molten plastic material is pressed around each die to form its individual package. The mould is opened, and the lead frames are pressed out and cleaned.

3.3 Lead finish: with electroplating the encapsulated lead frames are 'charged' while submerged in a tin-lead solution. This increases conductivity and provides a clean consistent surface for surface mount applications.

3.4 The trim and form process: lead frames are loaded into machines where the leads are formed step by step until finally the chips are severed from the frames. Individual chips are then put into anti-static tubes for handling and transportation to the test area.

3.5 Final testing / shipping: the packaged chips are re-tested to ensure that they were not damaged during packaging and that the die-to-pin interconnect operation was performed correctly. A laser etches the chip's name and numbers on the package. The finished chips are shipped to users.

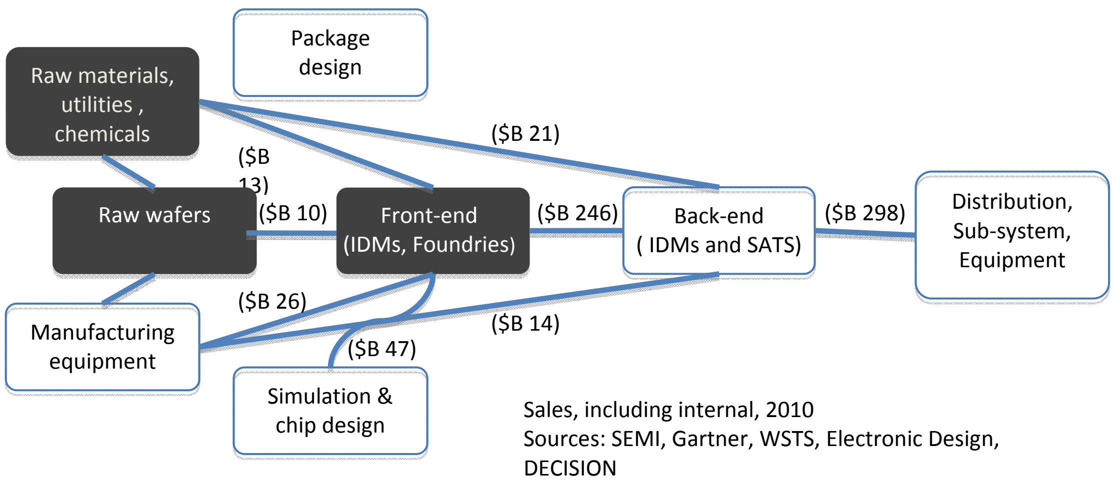
4 ***The users*** of semiconductor devices are either sub-systems assemblers or directly the end-equipment manufacturers. They buy the semiconductor devices either directly from the manufacturers (both IDMs or fabless) or from distributors. It is of course at this stage that any interruption in the semiconductor value chain can have an important impact, as the lack of a single device type can stop a whole end-equipment assembly chain.

In Figure 1.2, the parts heavily shaded can impact the whole value chain:

- Raw materials, utilities and chemicals;
- Raw wafers supply;
- Front-end: IDMs and foundries.

The numbers quoted give an idea of the sales between the various parts of the process. They are estimates for 2010 and can vary tremendously from one year to the other.

Figure 1.2 Semiconductor Value Chain



The literature and recent dramatic events in Japan make clear that the weakest points of the value chain are as follows:

1. Raw materials (used for manufacturing raw wafers, then in the transformation of wafers into chips, and again in the assembly phase) are critical in the process and are only produced in few places. They include silicon, germanium, gallium and boron.
2. The fabrication of raw wafers is complex and involves a large number of different materials and process steps. In addition to this complexity (and potential disruption in the raw materials, utilities and chemicals supply chain), 60% of production comes from Japan (source: IHS iSuppli Analysis, April 2011).
3. As far as (pure-play) foundries (companies with manufacturing plants but no design capabilities) are concerned, the main issue is their concentration in Greater China, i.e. Mainland China and Taiwan. This is a concern knowing that state-of-the-art production processes are highly concentrated in foundries, in companies producing memories, such as Samsung and Toshiba, and at Intel.

1.2 The competitive situation of the value chain

1.2.1 Internationalisation and fragmentation of the value chain

In-house offshoring of semiconductor assembly and testing started very early in the globalization process (company Fairchild was the first to move its assembly to Hong-Kong, in 1961), for cost as well as for labour quality and quantity reasons, because U.S. firms were under competitive pressure from Japanese competitors and this was the easiest part of the process to offshore. It was only in the late 1960s that the move to offshored outsourcing started.

Chips production offshoring (by U.S. companies) started later, in the 1970s, but for different reasons. At this time, trade barriers, especially in Europe (where semiconductor production had started in large firms, namely Philips, SGS, Siemens, Thomson) made U.S. exports to Europe (and Japan) uneconomic. During this period, U.S. corporations built many semiconductor plants in Europe.

Most authors place the real start of fragmentation of the semiconductor value chain in the early 1980s when the fabrication segment separated from the design segment, and fabless firms emerged. The root cause was the high cost of entry into the semiconductor industry, while the catalysts were the development of Electronic Design Automation (EDA) tools (1981) and of pure-play foundry fabs (the companies MOSIS and TSMC were created respectively in 1981 and 1987).

With the arrival of EDA companies, IDMs were able to outsource not only the computer-aided-design (CAD) tools they were developing themselves, but also some of their designs to a new breed of companies, the ‘design houses’. In turn, because the demand from IDMs was not steady, design houses started developing products of their own (thus creating the first fabless companies) and looking for companies to produce them. The first foundries were laboratories or small companies only able to produce prototypes and small volumes.

In the 1990s, the company TSMC then played a central role in the evolution of the semiconductor value chain as a pioneer in the foundry business. It remains the leader of pure-play foundries today with almost 50% market share (source IC Insights, Feb. 2011), and is also an established member of the top five manufacturers. Its presence and leadership have been one of the main reasons for the development of the semiconductor industry in Taiwan, as well as of the dominance of Taiwan in a number of IT equipment manufacturing sectors. "According to a survey (Deng, 2005), Taiwanese integrated circuits (IC) design firms use as much as 85% of local foundry services for their own products. This shows that "spatial proximity matters for the IC design industry and this in turn creates a cluster effect." (Interview with Professor Wang).

In the 1990s, the emergence of the so-called 'system-on-chip' methodology led to the disintegration of the design part of the value chain into EDA and Intellectual Property (IP)[3] providers and design houses. The fragmentation of design undermined the prevailing wisdom that off-shoring production of semiconductors was not a relevant business issue given that design, as the high value-adding part, remained in the country of origin.

During the last decade the long-term trend in fragmentation of the semiconductor value chain has continued. There are five main reasons for this:

- cost reductions by moving production to 'low cost' labour countries;
- the continued high rhythm of technological change, obliging companies to focus on core competencies;
- the migration of consumer goods production to Asia, encouraging the move of related semiconductor production;
- the low pace of company concentration in the semiconductor industry;
- the increasing cost of building and equipping fabs.

This decade has seen the emergence of the 'fab-light' model due to the increasing cost of building state-of-the-art fabs, which today are only affordable by a handful of IDMs (Intel, Samsung, Toshiba, Renesas, etc.) and foundries (TSMC, Global Foundries, SMIC, etc.). This new model makes the value chain more complex. 'Fab-light' refers to the move by a large number of companies from the 'fab' model of a full IDM manufacturer towards an intermediate model where they act as an IDM for only part of their sales and as 'fabless' for the rest (i.e. by outsourcing production to a foundry).

As mentioned by an industry leader (ElectronicsWeekly.com, Nov 10, 2010), "fab-light is a cashless strategy", as it is a way for an IDM to avoid investing in new manufacturing plant. Financial pressure from shareholders worried by insufficient results has triggered this successful short term financial strategy in most companies, as proven in the recent past by the financial results of the NXP and Infineon companies.

However there is a good case for the assumption that "fab-light is the way to fabless". The products that are manufactured by foundries for IDMs are state-of-the-art and require the latest manufacturing facilities. In time these products become commodity products and the older fabs become obsolete. The fab-light IDMs will close the obsolete plants and will most

[3] In electronic design a semiconductor intellectual property core, IP core, or IP block is a reusable unit of logic, cell, or chip layout design that is the intellectual property of one party. IP cores may be licensed to another party or can be owned and used by a single party alone.

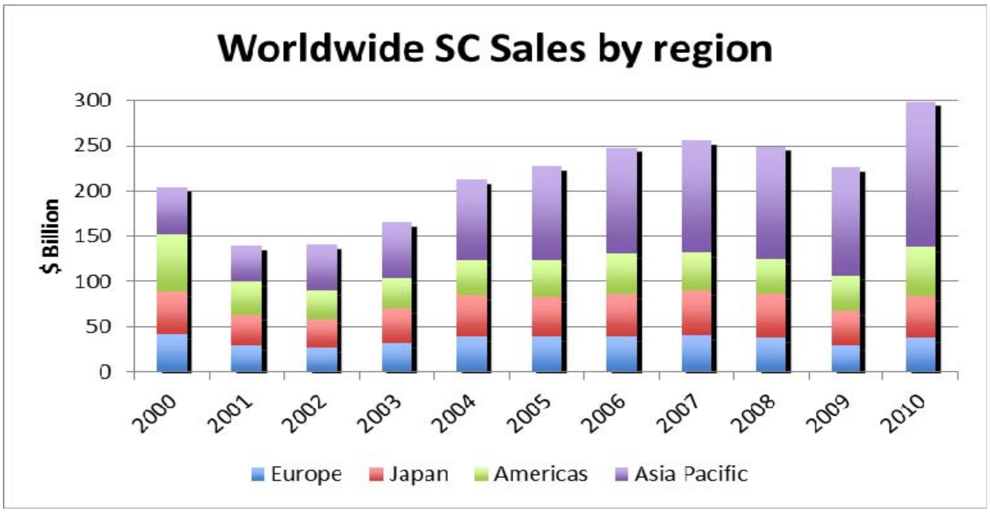
probably not have the cash (because, in the meantime they will have lost the human resources, know-how and equipment) needed to build state-of the-art new ones, so they are likely to become fabless.

Finally, this means that production will remain in the hands of foundries and the remaining full-fab IDMs (it is to be noted that "cooperative" foundries -supported by several companies- is a possible development). This in turn is likely to be the beginning of a large movement of consolidation in the industry.

1.2.2 European position in the semiconductor value chain

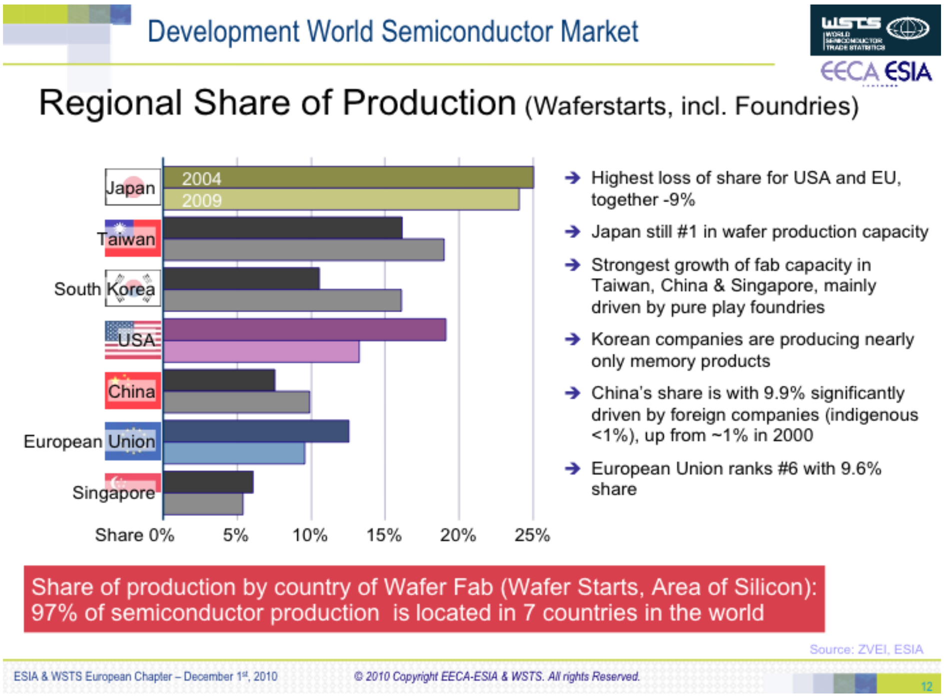
The evidence tends to show that the last decade has seen continuous and uncontrolled deterioration of Europe's position in the global semiconductor value chain, shown by declines in both production and consumption. The worldwide share of Europe as a consumer of semiconductors has been declining in the last 10 years: from a peak of 22% in 1998 to 13% in 2010 - and still declining.

Figure 1.3 World Semiconductor sales by region (source WSTS, 2011)



The decline of the EU-share of worldwide production has also been significant: from close to 14% in 1998 to less than 10% in 2010 (just above 10% excluding foundries). The EU now ranks 6th, behind Japan, Taiwan, South Korea, the U.S.A. and China. It is noticeable that all regions have lost share for the benefit of Asia-Pacific, which now represents more than half of worldwide sales, and that the US has lost even more share than Europe.

Figure 1.4 Regional share of Semiconductor production (source EECA-ESIA & WSTS), 2004 and 2009



It is clear that most parts of the semiconductor value chain are now located outside Europe. It is indisputable that there are a few bright spots in the materials and the equipment area, but many European companies are exporting most of their production because state-of-the-art manufacturing has migrated in order to get closer to customers. A major concern is that all production and then R&D could migrate outside of Europe for the same reason.

As such, offshoring and outsourcing are part of the history of the semiconductor industry and not specific to one region. The internationalization of the value chain has never been considered as a problem by corporations, but has from time to time caused reactions from governments (both within and outside Europe) anxious about employment and/or added-value losses due to the delocalization of production.

At the turn of the century there were three European semiconductor manufacturers in the world top ten (STMicroelectronics, Infineon, Philips). Today, there is only one.

Table 1.1 Semiconductor companies ranking 2000-2010 (not including foundries)

Rank 2010	Company	Country of origin	Revenue (million $ USD)	Rank 2009	Rank 2003	Rank 2000
1	Intel Corporation	USA	40 394	1	1	1
2	Samsung Electronics	South Korea	27 834	2	2	4
3	Toshiba Semiconductor	Japan	13 010	3	5	2
4	Texas Instruments	USA	12 944	4	4	3
5	Renesas Electronics (1)	Japan	11 840	9	3	NA

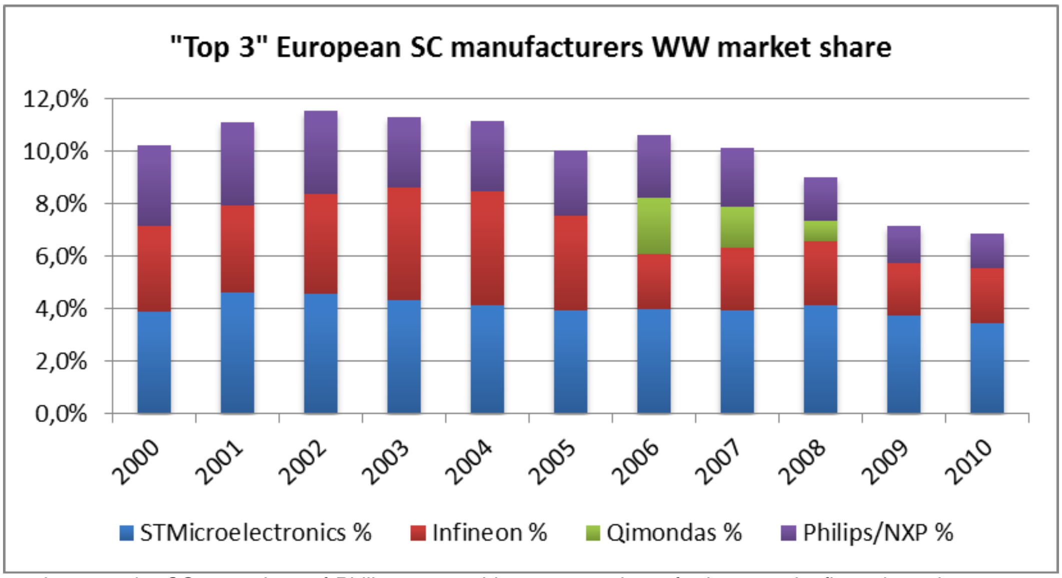
Rank 2010	Company	Country of origin	Revenue (million $ USD)	Rank 2009	Rank 2003	Rank 2000
6	Hynix	South Korea	10 577	7	16	14
7	STMicroelectronics	France/Italy	10 290	5	6	6
8	Micron Technology	USA	8 853	13	14	10
9	Qualcomm	USA	7 200	6	19	25+
10	Broadcom	USA	6 506	14	20+	25+
11	Elpida Memory	Japan	6 678	15	20+	25+
12	Advanced Micro Devices	USA	6 355	8	12	16
13	Infineon Technologies	Germany	6 226	11	7	8
14	Sony	Japan	5 336	10	13	20
15	Panasonic Corporation	Japan	5 128	18	25+	25+
16	Freescale Semiconductor	USA	4 329	17	9	7
17	NXP (Philips)	Netherlands	4 021	19	10	9
18	Marvell Technology Group	USA	3 680	23	25+	25+
19	MediaTek	Taiwan	3 595	16	25+	25+
20	NVIDIA	USA	3 189	20	25+	25+

(1) RENESAS = Mitsubishi + Hitachi (in 2002) + NEC Semiconductor (in 2009)

Source: iSuppli, 2000, 2003, 2009, 2010.

During the 1990s, Europe saw growth in new fabs but since then the flow has reversed, and the region fell significantly behind in semiconductor manufacturing during the last decade. Old fabs closed with few new ones opening to replace them. The reason is that European semiconductor companies have all taken the ‘fab-light’ approach based upon the assumption that in-house production was both too expensive and unnecessary, with no strategic or commercial benefit.

Figure 1.5 Major European SC manufacturers market share (source IHS iSuppli)



Note: in 2006, the SC operations of Philips were sold to a consortium of private equity firms through an LBO to form a new entity named NXP Semiconductors. The same year, the memory activities of Infineon were spun off to form a new separate legal entity named Qimonda.

However, Europe remains a world leader in many aspects of supply to the semiconductor industry, mostly due to successful European Commission supported basic research. For example, ASML based in the Netherlands and supported by research at IMEC in lithography, and SOITEC in supplying SOI wafers. RECIF is one of the world leaders at robotic wafer handling and companies like ASMI or AIXTRON win business worldwide in deposition technology. European R&D also remains world class. Many of these companies have found that most if not all of their sales now come from outside Europe. Consequently they often consider moving their operations closer to their Asian customers.

Table 1.2 Regional repartition of sales

Sales	2004		2010	
	Asia	*Europe*	*Asia*	*Europe*
AIXTRON	77%	9%	91%	4%
ASMI (Front-end)	21%	10%	32%	6%
(Back-end)	47%	1%	69%	1%
ASML	68%	12%	80%	5%

Source: Annual reports from the companies (provided by Cambridge Econometrics).

Fragmentation has therefore led to the rise of some industry leaders in Europe and the development of some excellent R&D centres (like LETI and IMEC), but also to the development of the fabless business model. For example, CSR, which just bought Zoran, is a very successful fabless company.

However European excellence in semiconductor R&D, a position endorsed by most interviewees, and the position of world leader in some parts of the value chain has not been enough to stop the decline of European market share in SC production. This is largely linked, according to the interviewees, to the increasing use of state aid in Asia and North America, and it seems most likely that the conversion of European companies to the fab-light model will accelerate this decline of production, unless strong foundry capabilities are built in Europe.

The major concern related to the decline of the semiconductor production in Europe is, therefore, the risk that large parts of the value chain will move out of Europe, following their market. This includes some R&D, much of which is heavily funded by the EU.

This concern was raised in SEMI's October 2008 White Paper (page 1), which highlights that "Although system integration, R&D and small scale production might still remain in Europe, SEMI Europe members fear that without major semiconductor manufacturing, eventually knowledge-based activities will also relocate to other regions".

1.2.3 Other countries' strategies

Different regions have had, mainly for historical reasons, and still have different strategies concerning the semiconductor value chain:

- **The semiconductor industry was created in the USA**, following the invention of the transistor (Bell Labs, 1947) and the integrated circuit (Texas Instruments, 1958, and Fairchild, 1961). In the early stages, each company was an entire value chain in itself, but through spinning-off internal activities in order to focus on core competencies, a complete commercial value chain was created over time in the country. The US semiconductor industry, strongly supported by government (especially the military) at the start, was dominant until the mid-1970s when it was challenged by Japanese industry. A long commercial and diplomatic 'war ended with the 1986 Trade Agreement. Many such trade conflicts took place until the "Joint statement concerning semiconductors by the governments / authorities of the United States, Japan, Korea and the European Commission" of 2006. From the start of the industry until today, the US government has always considered the semiconductor industry as strategic.
  For this reason US authorities have never hesitated to intervene when the US semiconductor industry was in danger. Recent concerns are with Chinese competition and the decline of semiconductor manufacturing in the US. (See Figure 4.4)

  To a lesser extent the US semiconductor industry faces the same challenges as the European industry. Indeed, although offshoring by US companies and the internationalization of the value chain did create some "holes" (mainly in wafer production and assembly), most elements of the semiconductor value chain remain present in the US, which is not the case in Europe.

  The US authorities (and various professional associations) have always closely monitored the local semiconductor value chain, restricting exports of strategic products or equipment and vigorously reacting to anything they consider as 'unfair' competition, not hesitating to put pressure on foreign governments to bend their policies in the right direction.

  During the last decade the US has added the encouragement to manufacturing to their policy portfolio: "Research and Development takes place in close proximity to manufacturing. When U.S. companies set up manufacturing overseas, R&D follows. "US leadership in high technology is at risk if the manufacturing 'anchor' is damaged", says a study by the President's Council of Advisors on Science and Technology (PCAST) in July 2011. "The US economy cannot be dependent on 'knowledge' if its Research and Development is 'de-coupled' from manufacturing" (Centre for Public Policy Innovation, 2010).

Most recent developments in the US semiconductor manufacturing area come from the State of New York. In 2009, it promised $B1.2 in cash and tax breaks to GlobalFoundries (a direct competitor to Taiwan's TSMC) to build Fab 8 in Malta (NY) a B$4.2, state-of the-art, foundry fab. On September 27, 2011 Governor Cuomo announced that "New York State has entered into agreements providing for investments valued at a total of $4.4 billion over the next five years from five leading international companies to create the next generation of computer chip technology. The five companies involved are Intel, IBM, GlobalFoundries, TSMC and Samsung. New York State secured the investments in competition with countries in Europe, Asia and the Middle East."

- **Japan developed its semiconductor industry in the late 1960s** as a competitive challenge to the US, which restricted for strategic reasons the export of these devices. Japan relied on three pillars: rich human resources in applied physics; consumer and mass market oriented features (in contrast to the US where the government sector had a leading role); and labour discipline and organisation.

From a structural standpoint it must be noted that, while the US semiconductor industry grew in a 'free market environment' (even though a large part of the R&D was heavily government funded until the mid-1980s), Japanese industry was largely built on the two pillars of MITI (Ministry of International Trade and Industry) and Keiretsu (conglomerates).

Created in 1949, MITI was given the mission for coordinating international trade policy with other groups, such as the Bank of Japan, the Economic planning Agency, and the various commerce-related cabinet ministries. Until the early 1980s, MITI has served as an architect of industrial policy, an arbiter on industrial problems and disputes, and a regulator. A major objective of the ministry has been to strengthen the country's industrial base. Keiretsu are conglomerates set up around a bank (vertical keiretsu) or within an industry (horizontal keiretsu). The latter link suppliers, manufacturers and distributors within one industry.

Cooperation between MITI and the keiretsu allowed the funding of large but focused electronics projects whilst trade barriers were maintained to protect the nascent industry. This worked until the mid-1980s when the trade agreement with the US was signed. At that time the Japanese semiconductor industry had overtaken their US competitors.

With the decline of influence of MITI, the 1990s were difficult for the Japanese which again lost its world leadership to the US. It was only in 2002 Japan managed to become again the world leader in the semiconductor industry after manufacturers cooperated and heavily invested in 300mm manufacturing technology.

Japanese culture (again in contrast to the American) meant that semiconductor corporations retained all elements of the value chain within the country, so that the

Japanese semiconductor industry became largely self-sufficient. This led to worldwide dominance in some areas such as materials or wafer production or in some products (e.g. microcontrollers for automotive).

Until 2010, Japanese industry has retained its leadership in terms of production and to a large extent in terms of technological advance. However, the 2011 earthquake might be an opportunity for Taiwanese industry to wrest world leadership from the Japanese. Another consequence of the recent catastrophe in Japan is that some companies, which are mainly Japan-based, are considering offshoring part of their production facilities. Given that most of them are not willing to go to China or Korea, and as Taiwan has no more room, Europe and the US are the most probable candidates.

- **The Taiwanese SC industry started in the late 1970s** from state initiatives to develop the PC industry and to support it with a strong SC industry (already existing in the island under the form of US offshored assembly plants). It started with the creation of the Industrial Technology Research Institute (ITRI) in 1973 and the Electronics Research Service Organisation (ERSO) in 1974.

ERSO scoured the world for knowledge in IC manufacturing and obtained the transfer from RCA (Radio Corporation of America which disappeared in 1986) of its obsolete IC fabrication technology. In 1980 ERSO launched UMC (United Microelectronics Corporation) in Hsinchu Science-based Industry Park, which is now the heart of the Taiwanese semiconductor industry.

However, the leap forward was the creation of TMSC, the brainchild of Dr Morris Chang (who had 25 years' experience with Texas Instruments), in 1987. Dr Chang had understood the promising future of silicon foundries. The new company was a joint-venture with Philips which allowed the company to be at the forefront of technology. Today, TSMC is the leader in foundry process technology, whilst Taiwan's IC design sector is still a fast follower. The test and assembly sector is also the leader but depends more on low cost and product efficiency than on innovation. Geographical proximity coupled with a strong Chinese demand for ICs increased the links between Taiwanese and Chinese industry creating both an opportunity and a threat for the former, which is highly dependent on the latter in terms of manpower and raw materials.

In Taiwan (RoC), foundry pioneer and still global leader TSMC plays a special role in the semiconductor value chain. Taiwanese GDP is about 5% of the EU's, but its semiconductor production (including foundry) is twice as big at 18% of the worldwide total in 2010 ($B56, according to TSIA, March 2011; WSTS 2011; ESIA, figure 4.4). In 2010, Taiwanese foundries accounted for 69% of worldwide foundry revenue, with TMSC alone having just over 50% of global market share. Greater China[4] reached 80% of world foundry capacity (source DigiTimes, 2011).

Worldwide foundry revenues in 2010 represented about $B26 in sales (which means that Greater China's revenues from foundry are – 80% of $B26 – of around $B21). It is to be noticed that this figure needs to be inflated to be comparable with $B298 world

[4] Greater China is the RoC (Republic of China, Taiwan) plus the PRC (Peoples' Republic of China, or mainland China).

semiconductor sales; indeed foundry sales include only manufacturing costs and not R&D, marketing, etc. costs. As an indication, fabless revenues reached $B60, but fabless companies are not the only users of foundries; fab-light companies also use foundry. Taiwan represented 24% of worldwide fabless revenues and Mainland China 9% (i.e. for Greater China about $B22 in revenue). Taiwan is also (historically) an important place worldwide for assembly and testing

While RoC (and PRC) are fast followers in the fabless companies area (260 in Taiwan and around 500 in China compared to 160 in Europe and 1,300 worldwide), they are clearly leaders in foundry.

- **In the late 1960s and early 1970s,** US (led by Fairchild, Motorola and TI) and Japanese (led by Toshiba and Sanyo) semiconductor companies set up assembly plants in **Korea**, with the support of the Korean government and under the support of MCI (Ministry of Commerce and Industry). The Korea Institute of Science and Technology (KIST), which was in charge of the build-up of the countries 'absorptive capacity' for advanced technologies, closely watched these implantations.

The indigenous electronics industry in Korea started in the late 1960s when the Samsung Group (a conglomerate, or chaebol, with many diverse activities) decided to enter the electronics market and set up joint-ventures with NEC and Sanyo. After expanding into industrial and consumer electronics throughout the 1970s, 72-year old chairman Lee Byung-chull announced in 1983 that he was "betting the firm" on Samsung's ability to become a player in the VLSI memory chips industry. (A joint-venture between Goldstar and US National Semiconductor had failed in 1973). The company mass-produced its own 256k DRAM in mid-1986, at the beginning of a market upturn, making a lot of money. Hyundai closely followed Samsung but it was only profitable in the early 1990s.

At the start of the Korean semiconductor industry, the government managed to reserve the profitable part of the telecom industry market to the major chaebol involved and supported their VLSI activities through the publicly owned Korea Institute of Electronics technology (KIET). During the 1982-1986 period, the Korean government set up the "Long term Plan for the Promotion of the Semiconductor Industry" which included a public investment of $M400 and put pressure on the chaebol to make serious commitments.

After Samsung's success in DRAMS, the major chaebol offered start-ups in Silicon Valley very good terms for producing the products they had designed in return for the rights to licence these designs. This was the start of what the US Department of Commerce regarded as "technology leakage" to Koreans. By the late 1980s, Korean firms had firmly established themselves in the US market of DRAM memories, but were still critically dependent on Japan and the US for fabrication equipment and materials.

The 1990s have seen the consolidation of the industry, still with strong support from government agencies, through more commitment of the private sector to innovation, the broadening of the product range beyond memories, enhancing the supply of chips to the domestic market, the development of local equipment and materials supply, the expansion of production facilities abroad (Europe, China, US), and joint R&D projects. The only failure in this strategy is the lack of start-up development, mainly because of the chaebol. Disputes with the US started in the mid-1990s, when the US trade balance with Korea started to show a deficit, and were settled by the 2007 Free Trade Agreement.

In 2010 Samsung and Hynix (ex-Hyundai Electronics) were both in the worldwide top-ten. Due to their abundant financial resources, they continue to buy and assimilate technologies from abroad, are now creating their own new frontier technologies, and have established a leading position in many areas.

- **China's semiconductor industry** is the most recent. In 1999 it accounted for less than 2% of worldwide production, but 10 years later this had reached 10%, i.e. the same level as Europe, and with 300,000 employees. After a stagnant state-dominated era (prior to 2000) the Chinese subsequently adopted a new policy (based upon Circular – Guo-fa - 18, see ECOVIS, 2011) including partnerships between foreign investments and indigenous innovation. This was helped by the rising demand for semiconductors (largely from Taiwanese PC manufacturing off-shoring production to mainland China), and enabled the take-off, not only of semiconductor production, but also of a large part of the SC value chain (especially fabless companies).

  However, strong doubts still remain on the efficiency and sustainability of the actual semiconductor industry in China, although new strategies have been announced in 2010 under the auspices of "China's Program for Science and Technology Modernization" CENTRA, January 2011). The new policy directions (driven by the Ministry of Science and Technology –MOST) are two-fold:

  1. Promote innovative collaboration, including incentives to industry R&D labs, universities and research institutes to work together toward, in the short-term, "chips for use in supercomputers, competitive system on chip (SoC) products, and a central processing unit/operating system (CPU/OS) for a Chinese-made computer to be used for "security" purposes" and, in the long term, "general high-performance central processing units (CPUs), digital signal processing (DSP), system on chip (SoC) and development platforms, IP core design, and electronic design automation (EDA).".This includes attracting foreign R&D labs in China to participate to the project.
  2. Support Chinese IC enterprises, including direct funding for building new fabrication plans ($B7 spent between 2004 and 2010, $B50 planned between 2011 and 2020), plus restructuring the IC industry into 5 large companies and 10 medium-sized, as well as about 30 fabless companies.

  In support of these strategies, triggered by the examples of Silicon Valley and Hsinchu Science Park (Taiwan), the Chinese government is also promoting the creation of "National High-Tech Zones".

  More generally the Chinese government has active policies in terms of:

  - Procurement, known as the 'indigenous innovation products" policy. Although the government backed down from its more protectionist attitude of 2010, it is still not clear how easily foreign companies will have access to public procurement.
  - National standards (for instance the Ministry of Industry and Information Technology –MIIT- has developed the TD-SCDMA standard in 3G mobile

telephony to compete against US and European standards, and might be in good position to shape 4G technology).

- Intellectual property (IP): the PRC has recognised (while developing its "indigenous innovation" policy) that IP protection is necessary, although some observers doubt whether IP really is protected in China; others note that most technology transfer has been through business decisions rather than technology stealing (CENTRA, 2011).

It is questionable whether the current policies will be successful as China will increasingly face some socio-political issues both internally (salaries, working conditions) as well as externally (trade policies).

Last but not least, the PRC has commenced 'official' cooperation with the RoC, giving consistency to the concept of 'Greater China', which seems to be leading to some integration of both countries' SC industries.

Overall, it would be risky to draw any strategic conclusions for Europe from the different national industries and policies mentioned above. However, a number of facts can be highlighted:

- The semiconductor industry has developed and remains geographically close to demand, even though some countries have grown to the extent of becoming net exporters.
- All domestic semiconductor industries have started and continue to expand with the support of a strong national industrial policy taking into account the potential of the industry for future macroeconomic growth.
- While R&D is a key ingredient for a semiconductor industry, production remains the key driver for new technologies and state-of-the-art products.
- Almost by definition industrial policies induce distortions in competition and, for this reason, the worldwide semiconductor market is far from being a free or fair trade market.
- Most countries aim as much as possible for a complete domestic value chain, especially for strategic needs as no country can afford long supply shortages.

1.3 Critical factors

1.3.1 Justification of critical factors

An initial literature research showed that at least a dozen critical factors could have an impact on the semiconductor value chain. One key criterion for the final choice has been the existence of real-life examples, although implications for prospective European policy have also been taken into account. None of the critical factors shown in Table 1.3 is specific to Europe but all of them could have a critical impact on the European semiconductor value chain. The interviews conducted confirmed the relevance of the choice.

Table 1.3 Overview of critical factors in the semiconductor value chain

Generic critical factor		Problems identified in literature	Problems identified in work with value chain	Description
"Localised" risks, high density	Natural/ environmental/ sustainability	Natural catastrophes	• Earthquakes	Japan is a high seismic activity zone (example of 2011 catastrophe).

Generic critical factor		Problems identified in literature	Problems identified in work with value chain	Description
problems	Socio-political	Policy and regulatory changes	• National industry policies • Regulatory framework	Electronic industry highly dependent on rare earth elements (95% of reserves in China). Relationship between ROC (Taiwan) and PRC (mainland China) might change the competitive environment (impact on prices, strategic alliances...). Shortage of equipment/basic materials could induce specific regulation. Could be a way to negotiate specific agreements.
"Global" risks, ubiquitous problems	Competitive	Nurturing competitors	• Birth and rise of new competitors	Foundries are increasing their market share in production, led by TSMC thanks to fabless and fab-light companies. In the same time TSMC is developing its R&D and back-end capabilities as well as its fabless network.

1.3.2 Critical factor 1: natural/environmental sustainability

a) Risks:

In the last 20 years or so there have been four earthquakes (October 1989, Loma Prieta – California; January 1995, Great Hanshin – Japan; September 1999, Chi-Chi – Taiwan; March 2011, Sendai – Japan) and a major accident (July 1993, explosion in Sumitomo's epoxy plant) affecting the semiconductor value chain. If this series can be considered as statistically significant, one can predict a significant catastrophe in this value chain every 5 to 7 years. Other natural catastrophes have impacted (and might impact) the semiconductor value chain, such as the flood in Thailand mid-October 2011.

A large proportion of the world's semiconductor production and equipment manufacturers are located on what is sometimes referred to as the 'ring of fire' where, in geological terms, the Pacific Plate comes into contact with adjacent plates of the Earth's crust —Taiwan, Japan, California, and Oregon (Intel). Although in some of these locations much effort and expense has been expended on seismic preparedness, there is still much to learn from previous earthquakes.

The major risks identified (for the semiconductor value chain) are:

- short supply of key materials (e.g. chemicals and wafers) and utilities (electricity, natural gas, water, sewage);
- additional costs for companies affected (e.g. buildings, pollution) and consequent increases in insurance costs;
- price increases of these devices inducing production cost increases for customers;
- market shortages for some semiconductor devices (e.g. memories and microcontrollers) causing production stops at end-equipment manufacturers (e.g. automotive and telecoms).

b) Impact:

Although data are readily available to analyse the impact on the semiconductor industry (units shipped, billings, pricing), it is always difficult to have information from end customers.

An analysis of the three earthquakes previous to 2011 (Hutcheson, 2011) concludes: "As for billings, the effect looks generally more positive following a disaster. In the month after Taiwan's Chi-Chi quake, billings were 8% above average. Not only does this refute the hypothesis that there was a disaster-induced shortage, it also points to the sickening idea that disasters may be good for the industry as a whole! The problem is not the disasters — it is the supply chain's reaction to the news and predictions of shortages." "*Customers downstream from the chip makers wind up paying more for their chips and ultimately electronics*."

In the case of the 2011 catastrophe in Japan, most reports from the press, manufacturers and users give a similar story which can be summarized as: "no major problem for the value chain, which has been incredibly resilient". In the end most seem to agree that the impact on the semiconductor value chain will have been negligible. However it is unclear for us whether the economic crisis, which was already latent in March (especially in Europe), has played a role in smoothing the impact of the Japanese catastrophe.

The following reservations can, however, be made:

- Some prices increases (analogue ICs, memories, foundry) were announced directly resulting from the Japanese 2011 earthquake, in materials as well as in finished semiconductor goods;
- Companies like Boeing, BMW, General Motors, Sony-Ericsson, etc., confirmed shortages in key critical components resulting in many other customers being affected, although this is not publically stated due to business confidentiality;
- Inventories were being built up for manufacturing goods to be sold at Christmas 2011, so that any negative impacts should have appeared in September or October. Nothing special has been reported yet (end of October).

For prices, it has been announced that TI has increased the prices of a large number of its analogue devices (where it is the world leader) by an average 2%, following the damages to its Miho and Aizu-wakamatsu plants. TMSC is also said to have increased the prices of some parts due to the short supply of wafers coming from Japan. In the end it is the final customer that pays the bill.

The French "Observatory of the consequences of the Japanese catastrophe on electronics" reports that there has not been any measurable negative impact related to materials, chemicals or wafers supply. As a matter of fact, the only semiconductor parts which have been in short supply are microcontrollers provided by Renesas (40% of world production) and Freescale (19%, a large part manufactured in Japan), which have induced production stops at a number of automotive plants (PSA, Renault, Toyota).

When Japan's catastrophe occurred, most observers were already reporting that chips inventories were at a (too) high level, in the three-month range. These inventories acted like a shock absorber. Had the catastrophe happened during a shortage, the impact on the electronics industry and others (not only automotive) would have been devastating because many end-equipment production plants would have been stopped. One could then argue that the current economic downturn has offset the negative consequences of the Japanese earthquake for non-Japanese companies.

As of October 2011 it appears that the semiconductor growth for the whole year will be much lower than initially forecasted. How much this reduction of demand is related to the tragedy in Japan is still unclear. However it is most probable that some industrial outputs have been delayed between May and September because some components coming from Japan were lacking (for example for iPad2), that worldwide electronics industry output (and thus semiconductor demand) has been reduced by plants destroyed in Japan, and that the Japanese consumer electronics demand downturn has contributed to the worldwide slowdown (the Japanese themselves are large customers for consumer electronics).

As a (tentative) conclusion it can be postulated that:

- Until now no catastrophe/disaster seems to have created a major disruption in the worldwide semiconductor value chain;
- The individual semiconductor companies and/or their customers have been able to absorb the subsequent shocks and only a very close look at their financial statements could show the real impact on each company;
- An analysis remains to be made as to the competitive consequences of such shocks on individual companies. For instance, it is clear that in 2011 Korean companies have gained new customers and market share at the expense of their Japanese competitors.

c) <u>Mitigation strategies</u>:

Most semiconductor companies have built mitigation strategies for catastrophe recovery, but, as one interviewee remarked in confidence: "plans are set up and implemented immediately after a catastrophe – the latest one being the Chi-Chi Taiwan earthquake – but as weeks, months, years pass, the details are more or less forgotten and the mitigation strategies are rarely fully operational when the next catastrophe comes".

A full mitigation strategy (for both semiconductor suppliers and customers) would include:

- multiple sourcing for materials and equipment (and regular supplier audits);
- inventories of materials as well as finished goods;
- security of power supply;
- a disaster recovery plan for each plant (and, even better, a 'continuity plan') with regular testing;
- good insurance against natural catastrophes;
- highly motivated employees.

Most of these strategies have been more or less in place as lessons learned in the semiconductor value chain down to distributors since Japan's Great Hanshin (1995) and Taiwan's Chi Chi (1999) earthquakes. Major progress has been made in anti-seismic buildings and multiple sourcing. After 1995, some Japanese firms have also delocalised production for both security and cost reasons. In the light of the March 2011 Japanese earthquake and tsunami, the electricity supply issue was more difficult to solve and should be considered, as should water and chemicals supply. In addition it is most likely that such mitigation strategies should also be extended to the end-equipment manufacturer level.

d) Governments/EU role:
Although the recent 2011 Japanese events seem to have had less impact on the semiconductor value chain than initially feared, there remains a need to consider the implications and risks for Europe. The starting point for this could be:

- There are other Asian regions where a high concentration of specific production could create a major disruption in the value chain, namely Taiwan and Korea;
- The major issue in Japan has been the electricity supply (in general infrastructures are key) and, to a lesser extent, water supply.
- Japanese companies are considering building plants overseas (anywhere, it seems, apart from China), because labour costs are no longer the issue although IP security remains so.

It might be an opportune time for Europe to consider encouraging some Japanese (and Asian) manufacturers to offshore part of their semiconductor production value chain to Europe (especially in the case where there is no European competitor) by offering them the relevant infrastructures and incentives. Improving the security and efficiency of electricity and water supplies could clearly be the basis for a longer-term mitigation strategy, and this is also necessary for other industries and for citizens. This could be developed through the "European Smart Grid initiative" (JRC- Institute of Energy, 2011) and "Roadmap to a Resource Efficient Europe" (European Commission, 2011).

1.3.3 Critical factor 2: socio-political

China's semiconductor market has grown from zero in the early 1990s to more than one fourth of the worldwide market in 2010. Its production capacity has grown close to 9% of the global total, i.e. about the same as Europe's according to ESIA. For these reasons China, is now a key player. In 2011 China launched its 12th five-year development plan (2011-2015) that lays out the challenges the country faces in short-term macroeconomic management and longer-term structural transformation. It also places "rare earth and high-end semiconductors" as one of the main industrial priorities. This situation makes Chinese industrial policy a major factor in the evolution of the semiconductor supply chain and potentially a major risk for the European part of it.

a) Risks:
The "indigenous innovation policy" of China concentrates a number of these risks and has raised concerns that it is ultimately denying foreign firms access to business opportunities. The numerous incidents surrounding the rare earth issue and their price increase (some prices doubled during first half of 2011) and the increasing links between Taiwan (RoC) and China (PRC), via the "Economic Cooperation Framework Agreement" (ECFA), have increased these fears.

The aim of the 'indigenous innovation policy" is to actively build a number of state-owned companies into "national champions" which are large and technologically advanced enough to compete with world market leaders. The Government's procurement practices and technical standards, willingness to provide funding to Chinese SOEs, and, potentially, the enforcement of the anti-monopoly law, are combining to create powerful Chinese companies that can become market leaders in high-tech industries. The risk to Europe is four-fold:

- Reduced supply of some materials (rare earths) where China has a quasi-monopolistic position;
- Restricted access to a fast growing market (indigenous innovation policy);
- Increased risk of technology leakage, Intellectual Property Rights (IPR) infringement.
- Potential emergence of new competitors.

In summary, the worst case scenario would be that the European semiconductor industry faces a situation where they have restricted access to the (biggest world) market (indigenous policy), while Chinese policy would nurture future competitors, limit the supply of critical materials (or at a high price) and cause European IPR to be infringed and/or their products counterfeited. These risks have a high probability of materializing in the absence of proper mitigations strategies.

b) Impact:

Clearly, the raw material and rare earth issues have and are going to have an impact on prices. However, for the time being this impact is relatively small and can be offset by manufacturers' margin reductions or end equipment price increases. In the longer term, however, it raises the issue of finding new sources (which is rather difficult when mining is involved) and/or making serious efforts to recycle materials used in mass-produced equipment, such as mobile phones, on pain of reserving these markets to the corporations having home access to these materials.

In this sense, this situation contributes to the indigenous innovation policy which aims at developing 'local champions' strong enough to compete efficiently in the world market. The examples of the major Chinese companies' success in computers and telecommunications demonstrate that this is not only a fear but also a strong possibility. In other words, taking into account the actual slow but continuous disaggregation of the European semiconductor value chain, Chinese policy, if not counterbalanced by efficient mitigation policies, could be the factor that pushes the European semiconductor industry out of the leading pack.

c) Mitigation strategy:

As far as supply is concerned (materials, rare earths), the mitigation policy is multiple sourcing. The issue for companies is that they have little means of rapidly accessing new sources when one country controls production (although not reserves). This is the reason why today the fastest way of finding second-sources is to recycle these materials where possible. Recycling in the electronics area is very low but private companies are starting to address the issue. Companies can also have their home countries or the EU raise the issues at WTO. Trade dispute cases, like the ones discussed here, are initiated by the EU this is what happened with the raw materials case, where the EU launched a case against China's use of restraints on the exportation of a set of raw materials. This led to the WTO ruling on July 5th, 2011, but the case is now in appeal.

The general issue of China's policy is one that cannot be tackled by individual companies. The only mitigation strategy for companies is to closely monitor China's policy, to complain at states level when needed and to ask for political issues to be resolved. China's officials are not closed to discussion as showed by the repeal of three national indigenous innovation-related policies, which entered into force on July 1 2011.

Paradoxically ECFA, which could potentially lead to an increase of IPR infringement and of product counterfeiting by allowing more circulation of goods between RoC and PRC, might also be a mitigation strategy for European firms having establishments in Taiwan. Indeed, with the IPR agreement under the ECFA, Taiwanese companies or Taiwanese subsidiaries of foreign companies may now enjoy treatment in China that might be better than that afforded to a foreign company directly invested in China.

d) Governments/EU role:

As mentioned above, the semiconductor case is one where the actions of governments and of the European Commission can play a decisive role in supporting the European semiconductor value chain. Key areas of action are:

- Monitor Chinese trade and investment policy;
- Lobby for free markets and resources access;
- Speed up China's accession to World Trade Organisation's Government Procurement Agreement (WTO's GPA) and strictly monitor its implementation and reciprocity;
- Help standards (of all kinds) definition in Europe;
- Secure sources of critical raw materials and encourage their recycling (the recast of WEEE directive, issued on July 29, 2011, should help).

Some interviewees expressed the wish that the EU would not be too "naïve" in its application of WTO rules and mentioned, for instance, that opening public procurement markets too widely or too quickly, while other countries (and not only China) do not reciprocate, is a risk to European industry and jobs.

1.3.4 Critical factor 3: competitive

a) Risks:

While the drive for more efficiency and cost reductions has forced disaggregation of the supply chain, technical complexity requires more integration as process nodes are shrinking. For economic reasons IDMs are going fab-light or fabless, and for technical reasons foundries are getting closer to their customers.

The Taiwanese company TSMC itself is struggling with reducing margins because of growing competition from Samsung and Global Foundries. The company has increased its R&D budget, is proposing its own IPs and is investing in back-end operations ("More than Moore" oriented), thus getting closer to becoming an IDM.

As major European semiconductor manufacturers are going fab-light, it is appropriate to have a closer look at this business model. "This means that existing production capacities are retained and that newly developed semiconductors, which require more modern manufacturing procedures - for instance, as a result of very small feature sizes - are manufactured by partner companies." (PwC). In other words it is a "no-cash strategy" aiming at reducing costs by outsourcing (and often off-shoring) some production while keeping inside design and sales. This is based on the hypothesis that most of the added value (and the financial reward) is not in the production phase.

This strategy provides good short-term benefits for companies' profit and shareholders (the cases of NXP and Infineon are significant), but it still needs to be assessed for its long-term effects. Although some (brilliant) analysts have described the fab-light model as a path to fabless and argued that fabs have a strategic value, there have up to now been few arguments raised against the model. Although the pros and cons of the model would require an in-depth analysis, there are some facts that should be considered:

- Considering that design is the "noble part" of the value chain and that who masters this phase masters the whole process (and the profit) is a mistake as it has been demonstrated by the end equipment industry: the companies (most of the time Chinese) to which production had been subcontracted tend to end up mastering the whole process, from design to sales (e.g. TV, mobile phones, ...);
- Letting others master the state-of the-art production technology is not a viable long-term strategy: in the semiconductor arena. A new process technology renders the previous ones obsolete, which means than in five years fab-light companies will have been transformed into fabless companies. From a European standpoint it means that "old" fabs will close one after the other within a few years;
- Most multinational companies are suspicious about off-shoring to Taiwan/China, and take as many precautions as they can, but the situation of the semiconductor industry is specific because Greater China has a quasi-monopoly in foundry. In practice, this means that state-of-the art production technology is mostly located there and that the most sophisticated (sensitive IPs) products (designed by fabless companies and now by fab-light companies) are also manufactured there;
- Even from a business standpoint, depending upon a quasi-monopoly is a short sighted strategy: the supplier can then dictate the conditions, raise prices and choose the customers it wants to favour. In the recent past, TSMC has developed its design and back-end capabilities, which is a major threat to some of its customers despite their denials;
- Last but not least, many experts agree that as geometries go further down (Intel demonstrated actual systems based on 22 nanometres parts in May 2011) the links between design and production processes will need to tighten, forcing companies not able to conclude cooperation agreements out of the market and those remaining to give more and more information to the founders (Source: interviews).

In summary, the fab-light business model followed by all the major European IDMs (and many others) is a 'no-cash strategy' that aims to improve margins by outsourcing the (currently) razor-thin margin production area. These moves, which make sense from a short-term economic standpoint in a perfect market, present some longer-term risks related to the high concentration of foundries in Taiwan (and Greater China).

These long-term risks contribute to nurturing competitors through:

- The power of a monopoly to influence the destiny of its customers is well known, and the choices made in terms of delivery, pricing and access to state-of-the art production technology, which can nurture some customers at the expense of others and/or the monopoly itself. This applies to suppliers as well;
- The destiny of an innovative product is to be imitated and copied. In the semiconductor area, there are two levels of protection, IP and manufacturing. Outsourcing production means giving to the manufacturer a large amount of information which is at the heart of

the product design and often highly confidential. The ‘time-to-copy’, despite all precautions, is thus significantly reduced and the innovation (R&D) made by one company diffuses very rapidly to others.

All the interviewees agreed that this risk is highly probable in the long term if nothing is done to change the current situation. However, it may be possible to reverse it within the next three to five years.

b) Impact:

While fabless and fab-light companies are very well aware of the risk of nurturing competitors and admit, “it is happening”, they are not really able to measure the impact. At the current state of the industry, the short-term economic benefits (to shareholders) of going fab-light offset the longer-term risk of nurturing (directly or indirectly) competitors, at least until recently. Corporations in the Western (opposite to, for instance, to Japanese or Chinese) world are little concerned by long-term strategies and not at all by the location of their premises and employees.

There are indeed some signs indicating that fabs might become more popular again. At least some companies, which were early adopters of the fab-light model, are reconsidering their strategy to protect their business but also their innovations. From a European standpoint, the question is whether efforts to support a high level of technological R&D benefit non-European competitors producing outside Europe in the absence (or decline) of European state-of the-art production. There are no hard facts proving this point but it is clearly a risk.

c) Mitigation strategy:

Many companies acknowledge that the fab-light model, under current conditions, is a “dangerous strategy” which needs to be closely monitored and controlled. Current mitigation strategies include:

- Negotiate preferential agreements with TSMC;
- Monitor closely the production process to ensure supply, quality and security;
- Diversify (when possible) their foundry sources (Samsung, GlobalFoundries, etc.), which means, in the current situation, help the development of TSMC competitors (e.g. through IBM’s Common Platform).

From an external point of view it seems that European companies should also cooperate to ensure the diversity of foundry offer.

d) Governments/EU role:

Dieter Ernst points out that “technology leadership strategies are extremely risky and market prospects are highly uncertain” and suggests (for Taiwanese “fast followers”) “technology diversification as a complementary option”, building on technologies that need not be new or difficult to acquire. Based on this remark and on the work done by the High-Level Expert Group (HLG) on Key Enabling Technologies (KETs), the Governments/EU role could be threefold:

- Encourage the development of end-products (in the key market already identified for the European Union, such as health, security, automotive, etc.) using proven semiconductor technologies which can be produced effectively in Europe, for the benefit of semiconductor suppliers and customers;

- Contribute to the building of the semiconductor "Three Pillar Bridge" proposed for KETs by the HLG, i.e. "Technological Research", "Product Demonstration" and "Competitive Manufacturing". This would support the development of home-based industry at all stages and make sure that EU R&D efforts do not nurture competitors in the long-term;
- Support, if possible, the development of a competitive source to Taiwanese foundries in Europe.

1.3.1 General comment

The three critical factors considered above (natural/environmental/sustainability, competitive and socio-political) are considered to be independent of each other by the interviewees although they share common points.

There is clearly scope for recycling in the materials area but also in the equipment area where older equipment can be (and often is) recycled (refurbished) for laboratories or less demanding technologies. Recycling even becomes obligatory in the case of restricted access to some materials. This shows (among other examples like metals recycling) that recycling should not be considered only as a mitigation strategy but also as a business, i.e. as an opportunity for employment and growth.

The interviews highlighted the importance and vulnerability of SMEs in the SC value chain (this is developed in a recent Sector Fiche of DG Trade). The innovative role of SMEs all through the ICT industry is well known but their role as suppliers to the semiconductor value chain is less documented. The interviewees stressed the fact that their access to funds, whether they are private equity or EU aids (considered as too complex to access) is an issue that makes their strategies difficult to deploy. Basically, large companies make their own strategy while SMEs always have to adapt their strategy to a changing environment. In addition, large companies "can make mistakes" and survive while a strategic mistake for a small company is typically synonymous with death. In Europe it can generally be said that large corporations are at the end of the value chain. Another key issue for SMEs is the protection of their IPR. Last but not least, while "Close cooperation and networks between SMEs and global actors, in manufacturing, services and applications, is important for the EU's competitiveness also in this sector" (DG Trade), such cooperation is still considered as too weak for a number of SMEs.

Outsourcing is the result of 'concentrating on core competencies'. Off-shoring is the result of lack of competencies or costs being too high in the country/region of origin. Both can work independently. All interviewees pointed out that the high exchange rate of the Euro (vs. the U.S. dollar and vs. the Yuan) is a major factor contributing to the high cost of production in Europe.

Natural catastrophes are considered as an existing risk, especially in Japan, Taiwan and Korea. Companies consider second sourcing as a relevant mitigation strategy (already more or less) in place, except for Taiwan whose quasi-monopoly in foundry is also an issue.

Nurturing competitors is not a factor for large corporations because they consider that it is part of their 'market conditions' as long as these conditions are 'normal' in respect of IPR, open access to market, etc. This can be an issue for Europe when publically funded R&D is involved.

The major risk identified by the interviewees over the next three years is in relation to critical materials, especially rare earths. This is closely related to the fact that most companies, especially if acting individually, have no means to control socio-political critical factors. In this case governments/EU help is clearly required (including support for recycling).

Table 1.4: Critical factors summary

Critical factor	Risk	Impact	Mitigation	Government/EU role
Natural disasters (e.g. Japanese earthquake, 2011)	- Short supply of key materials. (wafers, chemicals). - End-equipment production stops. - Price increases. - Additional costs.	Low to Medium.	- Second sourcing. - Inventories. - Disaster recovery/ continuity plan. - Autonomous power supply. - Insurance - Motivated employees.	- Encourage Japanese manufacturers to offshore production to Europe. - Improve security and efficiency of electricity (and water) supply - Support foundry development in Europe
Socio-political (e.g. Chinese industrial policy)	- Restricted access to some materials (rare earths). - Reduced access to markets - Development of new standards outside Europe. - Counterfeiting (as a collateral effect of Chinese industrial policy) - Difficulties in enforcing IPR (patents) - Emergence of new competitors	High in the long run.	- Avoid offshoring latest innovations and overall system integration. - Secure materials second sourcing (rare earths). - Push political authorities to reach long-term, stable agreements with China.	- Monitor Chinese trade and investment policy. - Lobby for free markets and resource access. - Help standards (of all kinds) definition in Europe. Speed up access of China to WTO's GPA and strictly monitor its implementation and reciprocity.
Competitive: nurturing future competitors (e.g. Taiwanese foundries)	- Monopolistic market (prices, preferences). - Be out of the race of state-of-the-art technologies. - Lose more parts of the value chain (including R&D). - European funded R&D leakage to foreign competitors.	High in the long run.	- Negotiate preferential agreements with TSMC/UMC - Closely monitor production process (supply, quality, security). - Diversify sourcing (including encouraging the development of smaller competitors/ new entrants).	- Integrated policy between semiconductor and end-equipment (KETs three pillars bridge). - Help maintain a minimum state-of-the art production capacity in Europe. - Encourage development of end products using proven mature technologies.

1.4 Critical regulatory framework conditions

1.4.1 Regulatory conditions in Europe

The evidence in this section is derived mainly from the interviews.

On the positive side (aid, regulation, programmes):

- Support to R&D: despite some complaints from SMEs that EC aid is too complex and sometimes easier to obtain by foreign companies than by local ones, the end result is that the EC has done a really good job in supporting semiconductor R&D and keeping it at world level. This support however failed to trigger the increase of local production, which could have been expected from these R&D achievements;
- Support to end-equipment: the initiatives that helped define and support the key end equipment have been useful and valuable. However, this did not translate into a demand for local semiconductor production. There is a missing link between successful R&D, on the one hand, and good definition and eventual production of advanced end-equipment and increased semiconductor production on the other – termed the 'valley of death';
- Efforts in critical materials: it appears that the EC has addressed in time what the value chain actors believe will be the critical factor for them in the next three years. They are expecting this effort to be pursued in order to ensure the security of supply of these materials;
- Key enabling technologies: the effort in definition of, and support to, related R&D is considered as extremely positive. Still the actors of the value chain fear this will not be enough to maintain a significant semiconductor value chain in Europe in the absence of state-of-the-art semiconductor production. The HLG KETs final report (June 2011) has already received a warm welcome.

On the negative side:

- Competition regulation is often said to be meant for internal (European) competition but to be at the disadvantage of the local actors vis-à-vis the outside world;
- Investment aid regulation (whether from states or from the EU) is considered as naive and obsolete in a world where all regions tend to defend and support strategic industries by all means;
- Work regulation should be adapted to the sector. As an example in semiconductor production, there is a strong correlation between defects and number of shifts. For this reason many countries (including the U.S.A.) have authorized 12 hours shifts in the fabs (with relevant compensation);
- Environmental laws are considered as negative from a short-term, economic point of view but also as a positive advance for the longer term.

1.4.2 Regulatory conditions outside Europe

It is difficult to have precise information on non-European regulation affecting the semiconductor value chain. The reason for this is that strategic sectors most of the time receive state benefits and aid, which, without being illegal, are specific for the sector and difficult to measure. States are not willing to admit unofficial aid while individual companies consider that this is a part of their business, which is private. In addition no one wants to be accused of disobeying WTO rules.

Literature says[5] state/federal aid consists mainly of tax abatements, cash grants, and equity/capital investment with various combinations of these. The cost of labour and working conditions are also part of the attractiveness of some countries. As ‘the grass is always greener on the other side of the fence’, few inconveniences are mentioned except, in some cases the obligation to accept local participation, for example in China, which can become an issue when it means access to confidential information or the possibility to influence strategy.

Table 1.5 is a summary of the opinions gathered during the interviews. The opinions were unanimous on both the positive and negative aspects.

Table 1.5: Critical regulatory conditions

Regulation	Positive impact *	Negative impact *	Short/long-term impact
EU			
A support to R&D	+		Long-term
B support to end-equipment	+		Long-term
C efforts in critical materials	+		Long-term
D key enabling technologies	+		Long-term
E regulations on competition		-	Short and Long-term
F regulations on investments		-	Short and Long-term
G work regulations		-	Long-term
H environmental laws	+	-	Short and Long-term
Non-EU			
A Cash grants		-	Short-term
B Tax abatements		-	Long-term
C Capital/equity investments		-	Short and Long-term

** Positive and negative impacts are relative to the impact on the European value chain.*

1.5 Strategic outlook

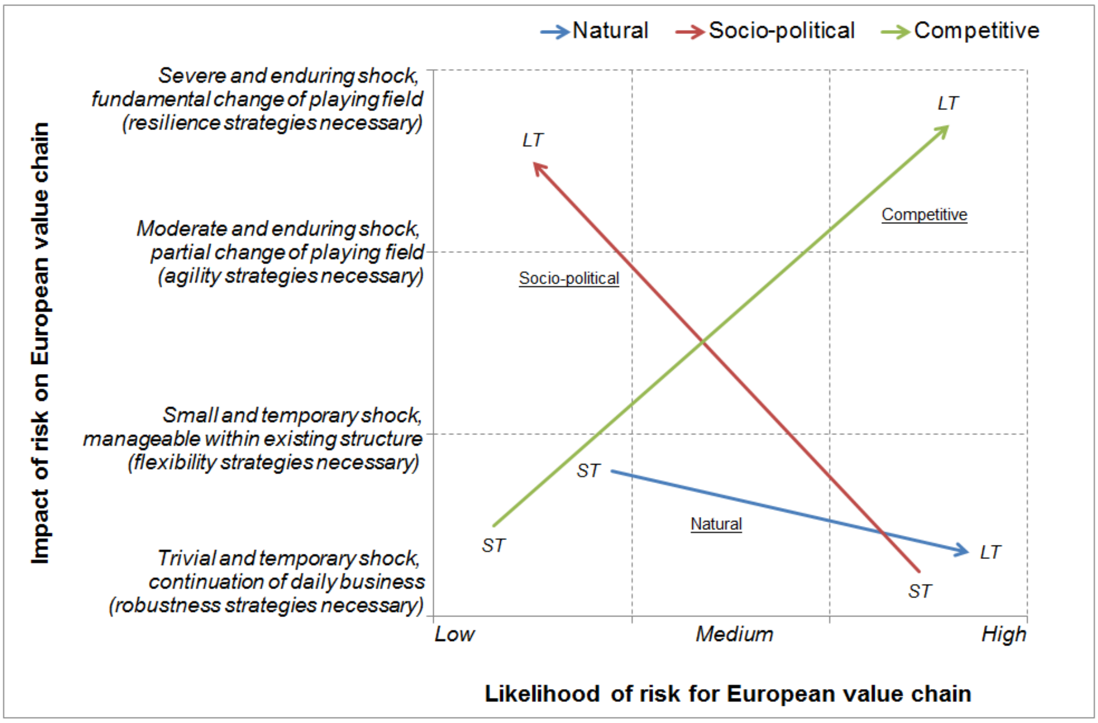
The different actors have different objectives:

- The objective of companies is profit: large corporations looking closely at quarterly profits and shareholder satisfaction while, at the other end, small companies look for cash and survival.
- The EC and Member States, despite the pressure of short-term events, look at the development of Europe (and states) with longer-term objectives of growth, employment, welfare, etc.

This is the reason for attempting to rank the various risks, in terms of probability as well as in terms of impact from a time perspective, as summarized in Figure 1.6.

[5] For example “Maintaining America’s competitive edge: government policies affecting semiconductor industry R&D and manufacturing activity.” Dewey & LeBoeuf for the SIA. March 2009; “China: Intellectual Property Infringement, Indigenous Innovation Policies, and Frameworks for Measuring the Effects on the U.S. Economy”, U.S. International Trade Commission, November 2010; “China’s Program for Science and Technology Modernization: Implications for American Competitiveness”, CENTRA Technology, Inc., January 2011.

Figure 1.6: Impact and probability of risks



It is extremely difficult to quantify both the probabilities and the impact value. Indeed nobody can give a number for the probability of a major earthquake within 3 years or imagine what could be the cost of a major change in Chinese policy. It is easier to determine whether, over time, the probability of a risk to happen and the cost of it happening is increasing or decreasing. This graph is thus not intended to give any "real" value impact of the various risks but only to rank them in the short-term and longer-term as well as show how the probability might evolve.

Catastrophes: the probability increases with time that large natural catastrophes will hit some regions (highest probabilities are in Japan, Taiwan and Korea) and impact the European value chain. On the other hand, however, the impact would tend to stabilize or decrease, other things being equal, thanks to mitigations strategies that are largely in place.

Socio-political: the risk already exists but at a rather low level as incidents are rapidly settled (usually via the WTO). The risks of such incidents decrease as Chine enters the free-trade world; however if incidents were to happen in the longer-term, there is a high probability that they will be more serious and have greater impact.

Competitive: the risk of nurturing competitors generated by the Taiwanese foundry quasi-monopoly will increase over time to reach a significant level (and market share loss) unless state-of-the art production capacity is set up in Europe. This would require a change of business model by major manufacturers and/or public help.

The "best" risk is the one of which the probability *and* the cost are decreasing. The "worst" one is the one of which the probability *and* the cost are increasing. If we follow this assumption, the risk that should be tackled urgently is the competitive risk, which can be summarised as follows:

Since the turn of the century the decline in the EU share of the worldwide semiconductor market and production has led to a slow but real disintegration of the European value chain. This is largely due to the choice, made by the major local companies, of the fab-light business model for economic reasons. In the case of semiconductors, because of the quasi-monopoly of Taiwan in foundry, this choice implies both outsourcing and offshoring. The decline of European production drives (or might drive) the offshoring of some parts of the value chain, including, in certain cases, R&D.

Table 1.6 summarizes potential strategies for governments/EU:

Table 1.6: Strategic outlook summary

Critical factor/ Case study	"Japan"	"Taiwan "	"China"	Governments/EU role
Natural/ Environmental/ Sustainability	X	X		▪ Encourage Japanese companies to offshore to EU ▪ Improve security and efficiency of electricity (and water) supply ▪ Support foundry development in Europe
Socio-political		X	X	▪ Monitoring Chinese trade and investment policy ▪ Lobbying for free markets and resources access ▪ Speed up China's accession to WTO's GPA and strictly monitor its implementation and reciprocity ▪ Help standards (of all kinds) definition in Europe ▪ Secure sources of critical materials ▪ Encourage raw materials/waste recycling
Competitive		X	X	▪ Help development of "relevant" end-equipment ▪ Help build the "three pillars" of KETs

An additional finding from the study is that most of the interviewees consider that, without state-of-the-art production in Europe, important parts of the value chain (equipment, but also R&D) might migrate closer to the latest technologies (in Japan, Taiwan, Korea, or the US). The solution to this problem, taking into account the choice of the fabless model by the major European companies, might go through some public support to state-of-the-art foundry development in Europe.

All the interviewees also consider that the following steps are needed to maintain a significant presence in the semiconductor value chain:

- Recognition of the strategic importance of microelectronics by the EU and Member States
- Agreement between them to promote this industry in Europe regardless of local interests
- A review of investments rules by the EU in order to allow "the right investments in the right place at the right time"
- Lobbying action from sectors organisations with a coordinated objective and a common understanding of the interest of the entire value chain.

Also according to the interviews, many companies do a good job even though they are not at the forefront of the technology (e.g. small foundries). These are also vital for the future of the value chain. Indeed while a supply chain cannot survive without continuous injection of technology and R&D, its basis remains the "current business" which fulfils basic needs. More mature technologies (power, analogue) also support the bulk of the market and, although not progressing at a fast technological pace, should be supported. It is to be noticed that most of the companies concerned are SMEs.

Finally, the interviews and the literature review enable a SWOT analysis to be drawn up, as in Table 1.7.

Table 1.7: SWOT of the European semiconductor value chain

Strengths	Weaknesses	Opportunities	Threats
• High R&D capabilities • Industrial base • Successful clusters • "More than Moore" • Education (skills) • Some strong market segments: auto, industry, and telecoms. • Competence in analogue and mixed-signal. • Market leaders in some equipment and materials (lithography, SOI, diffusion, deposition). • Some areas of strengths (smart cards, MEMS...) • Highly skilled employees, professional experience. • Still one of the industry leaders is European.	• No recognition of SC strategic importance. • Insufficient alignment of member states on a common semiconductor strategy. • Lack of European industry policy. • Failure in transforming R&D into sellable products. • Manufacturing industry missing hi-tech products focus. • Lack of investments in manufacturing. • Incentives limited by State Aid regulation. • No charismatic leader in S/C industry. • 40 % less patents than USA or Japan.	• New societal challenges, new markets. • Creation and steering of lead markets by setting standards (e.g. GSM). • Exploit leadership positions (analogue/sectors). • Need for proprietary leading solutions in European industry. • Increased public procurement for stimulation of new markets. • Leverage the More-than-Moore. • Competitiveness not anymore linked to salaries. • Time to help investment ("do as the others"). • 450 mm?	• European regulations on competition/investment. • Dependence on non-European foundries • Loss of major parts of technology and production expertise. • Followed by degradation in leading edge R&D. • Loss of major parts of proprietary IP. • Brain drain to other regions. • Currency variations. • More losses in production/employment. • Missing of some links in the value chain. • Education deficit. • Costs of IP protection.

Inspired from "Vision, Mission and Strategy, R&D in European Micro-and Nano electronics", AENEAS/CATRENE, 2011; HLG KETs Working document, February 2011; and the findings above.

Although the SWOT analysis is related to the value chain in general and not only to the above studied risks, it clearly shows that the European SC value chain is under threat of disaggregating, by loss of expertise if nothing is done to retain state-of-the-art production *and* R&D (IP but also manpower and skills).

1.6 Annex 1: interviews

- Guy Dubois: Director, GDCL Management, guy.dubois@gdcl.fr
- Michel Brillouet: Deputy Director, Leti, michel.brillouet@cea.fr
- Laurent Roux: Chairman, Ion-Beam Services, laurent.roux@ion-beam-services.fr
- Jean-Pierre Delesse, President, LFoundry, jean-pierre.delesse@rhealtys.com
- Gérard Mathéron: Director, STMicroelectronics Crolles, gerard.matheron@st.com
- Laurent Bosson: Founder, LB Consulting, laurent.bosson@st.com

- Martin Spät, Director General, EECA-ESIA, mspaet@eeca.be
- Professor Jenn-hwan Wang, National Chengchi University, Taiwan, wangjh@nccu.edu.tw

1.7 Annex 2: data issues

Relevant Data Used

"Official" data, although existing for a long time, are difficult to use to describe a very complex and internationalized value chain.

One single integrated circuit can go through five or six countries between the beginning of its production to its sale to the end-user. This is the reason why a number of research companies (Gartner, IHS iSuppli, IC Insights, Future Horizons, DECISION Etudes & Conseil and others) have been compiling data (based on raw WSTS[6] data and "official" data) for many years in order to provide *consistent* international data. Indeed the main issue is consistency, not only for European data but, for the reasons mentioned above, between various country/region data.

This case study has therefore only used data coming from these various organisations in order to ensure some consistency between the various data sets (production, market shares, companies ranking, etc.).

Primary data sources for this case study were:
DECISION
Proprietary data from DECISION, including Value Added data over 1995-2015 was used to inform the likely changing demands made on the Semiconductor industry.

iSuppli
iSuppli data on sales of semiconductor devices, including integrated circuits, discrete devices and optoelectronics by the largest 20 companies worldwide (measured in current price US$) was used to identify national/continental shares of production amongst the largest firms, and the inference drawn that this was a representative sample of total production across all firms.

DigiTimes
DigiTimes provided data on foundry capacity by country, including Taiwan and Mainland China.

World Semiconductor Trade Statistics (WSTS)
WSTS provide data on production of and demand for semiconductors (again including integrated circuits, discrete devices and optoelectronics) by region (Americas, Europe, Japan and Asia) and by major categories of products, measured in current US dollars used to establish national shares of total supply/demand. This data can be treated as being very robust, as it is the WSTS actual data is the reference for all sector experts in the semiconductor industry.

[4] World Semiconductor Trade Statistics.

European Semiconductor Industry Association (ESIA)
The ESIA provided data on the production of Wafer Fabs, a subsector of the semiconductor industry, in [currency?] by major world region over the period 2004-2009, to illustrate the geographical distribution of production. This data is based upon the WSTS data, and can be assumed to be an accurate representation of the industry.

Annual accounts
Data on sales in US dollars was collected from the 2000, 2005 and 2010 annual accounts of AIXTRON, ASMI and ASML, to show the sales in Asia versus the EU.

Data gaps and requirements

Using a range of sources we have been able to identify an approximate size of the global market and the degree to which this is split across different national markets.

The difficulties in obtaining consistent global data mean that it has not been possible to identify global shares for individual detailed product codes, and although data is available on an EU level covering the production of individual products from the Eurostat PRODCOM data, and a good level of detailed trade data is also available from Eurostat's COMEXT database, the decision was taken in this case to use data from WSTS instead. The WSTS data is standard within the semiconductor industry - It is the basis for all consultants and all SC companies. It covers market by region for a very detailed list of products. Some less detailed information is also available by major country. There are two issues with Eurostat and other "official" data:

- the nomenclature of "official" data does not fit with the reality of the product evolution;
- they are difficult to compare with other countries/regions nomenclatures

PRODCOM/COMEXT data are useful for studying EU trends in isolation to the rest of the world. In order to examine the global picture consistency is required and the only common source to all analysts is WSTS. This ensures some (not perfect) consistency between various regions and various consultants.

The R&D data available from Eurostat is only available at the 2 or 3 digit level, which is insufficient to separate out those parts relevant to the aeronautics value chain (as preferred to other uses of composite materials, and in terms of final products separating aircraft from spacecraft and other vehicles). Other areas for which it would have been beneficial to have had data (but for which data was not available on a consistent basis) would be on the level of entry/exit barriers (looking at wage rates, required skill levels and possible economies of scale in regards to costs), market concentration and fragmentation in the value chain.

While PRODCOM is useful for the detail it provides, this is only for production. The SBS meanwhile, has data for some other indicators of potential interest, such as employment, investment, employment in R&D, purchases of inputs. But it has less industry detail than PRODCOM, making it more difficult, if not impossible, to build up a picture of a given value chain in detail or assess the impact of globalisation/fragmentation on other indicators. We explored obtaining 'global' production data from Euromonitor, a market research firm, but found that the data available even then was very limited. Euromonitor's database is coded to the 4-digit level, which is insufficient for the detail required in this study. Euromonitor would have been required to break down 4-digit SITC codes using proxy data to obtain the sectoral detail required, and rather than being available for all countries the data provided would have been for just 13 countries across the globe (admittedly, the major producers (EU5, US, Japan, BRICs, Canada, Australia).

Various statistical sources (including SBS) present some measure on the purchase of inputs, but just the total. It was not possible to break this down into the different types of inputs and/or whether these inputs are domestically produced or imports. Some useful indicators can really only be obtained at the firm level, especially with respect to: diversity of suppliers; fragmentation of stages; supplier relations.

With regard to investigating fragmentation in value chains, one useful source is I-O tables, but more detail is required. The I-O tables typically cover 60 or so industries, roughly equivalent to 2-3-digit level. This means, for example, that (manufacture of) 'Radio, television and communication equipment and apparatus' or 'Electrical machinery and apparatus n.e.c.' are distinguished, but the manufacture of semiconductors is not, because it is too specific/detailed. As a result, I-O tables are useful for building up a picture of a value chain at a broad level, but to build a more detailed picture, say for Aeronautics, support from other data sources would be required.

While data from global sources such as OECD or UN provide an element of consistency and allow for comparison across a wider range of countries, this generally comes at the expense of industry detail.

At the same time, better coverage of the BRIC countries would be beneficial, as current coverage of these in, for example, OECD is non-existent or patchy. That said, it would need to be allied to extensive product/industry detail to be useful.

When using/comparing national statistics offices, there can be differences in what they present, how they present it, and how the measure has been calculated. So on a general level, greater harmonisation among the methodologies adopted by NSOs would be of benefit.

Wages data is often available but in our experience not in the sectoral/product detail that Prodcom/Comext sources provide. It may be that this is sufficient for looking at wages along a value chain, but if it is not we are not aware of more detailed sources. Skills are even more poorly covered by data sources, in terms of both sectoral detail and the skill levels/types distinguished.

1.8 Annex 2: literature

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