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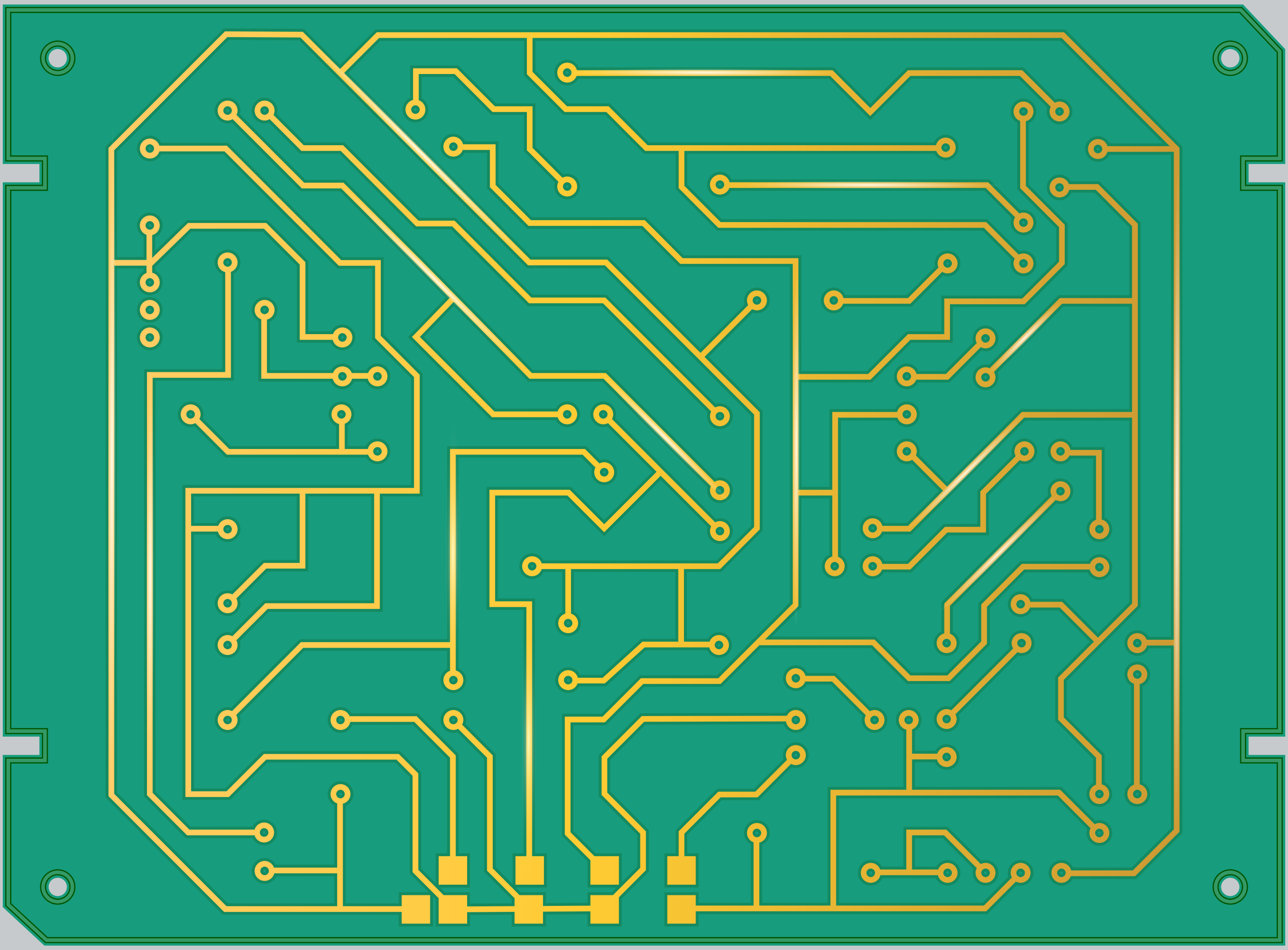
GLOBAL COMPETITION IN MICROELECTRONICS INDUSTRY FROM A EUROPEAN PERSPECTIVE: TECHNOLOGY, MARKETS AND IMPLICATIONS FOR INDUSTRIAL POLICY



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Global competition in microelectronics industry from a European perspective: Technology, markets and implications for industrial policy

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Content

1 Background and objective

1.1 Policy background

As a result of the economic crisis, a common perception among policy makers and consultants is that industrial policy has failed in the sense that it underestimated the importance of industrial production and manufacturing for the economy. It has been obvious that those countries that have maintained a strong and competitive manufacturing base did far better than average during as well as after the crisis (Reiner, 2012; Fürst 2013). Thus, currently there are serious concerns that the manufacturing base in Europe eroded too much (Warwick 2013). As a result, the "knowledge driven re-industrialization" of European economies became an important task; industrial policy experienced a revival and increasing the value added, as well as social welfare, by means of improved manufacturing capacities, became a new imperative among European policy makers (EUROPEAN COMMISSION 2013).

In doing so, the European Commission's focus on framework policies has been supplemented with more sector-specific policy objectives, in particular on six key enabling technologies (KETs): These comprise micro- and nanoelectronics, advanced materials, industrial biotechnology, photonics, nanotechnology and advanced manufacturing systems. Forecasts indicate that these markets together are going to grow by over 50 percent from €646 billion to over €1 trillion by 2015, which is equivalent to around eight percent of the EU's GDP (EU 2013). These sectors are assumed to be of key relevance for manufacturing and industrial sectors in Europe. Their support became a major rationale and strategic goal in European industrial policy. In doing so, the European Union attaches great emphasis to innovation-related industrial policy. However, firms and research organizations act under different legal, economic and sectoral framework conditions depending on their main technological and sectoral activity. Thus, designing appropriate mechanisms for state intervention requires a profound understanding of a certain technology's setting, including field-specific analyses, while taking sectoral as well as regional framework conditions into account. In doing so, this essay focusses on micro- and nanoelectronics (hereafter microelectronics), which is considered to be a strategically important multi-purpose technology for the re-industrialization strategy of the EU.

However, European economies and their policy makers are facing a set of challenges regarding microelectronics. Two main issues are discussed in this regard:

- Firstly, there is a common consensus that Europe has significantly lost and still is losing ground in the volume of state-of-the-art semiconductor-production capacities in relation to Asian economies.
- Secondly, legal framework conditions in the European Union cause a disadvantage for European locations particularly compared to Asian and US competitors.

Since most parts of the semiconductor value chain are nowadays located outside Europe, European Governments are worried that R&D, additionally driven by increasing state subsidies in Asia and North America, could follow and migrate outside of Europe. A major concern is that, due to the decline of semiconductor production, Europe risks losing large parts of the remaining value chain, unless strong production capacities are built. Among the remaining parts of the value chain is R&D, which is at least partly funded by the EU (Danish Technological Institute 2012).

As an answer to these developments, the European Commission published a "Multi-Annual-Strategic Plan for the ECSEL Joint Undertaking (JU)" in 2014. The main aim of this "Electronic Components and Systems for European Leadership (ECSEL) Joint Technology Initiative (JTI)" is to secure the supply of state-of-the-art electronic systems and components. It includes a strategy and roadmap to support the development and production of electronic components and systems as well as their integration in future key applications, labeled as Smart Mobility, Smart Society, Smart Energy, Smart Health, and Smart Production. While The EU plans to invest €1.18 billion through its research and innovation program Horizon 2020, at least a similar amount is expected to come from participating Member States. Further partners shall contribute at least €2.34 billion to public-private partnerships. The estimated overall budget is expected to reach approximately €5 billion.

In sum, the European Commission and its member states undertake ambitious efforts in order to strengthen their technological as well as industrial basis in microelectronics. However, this is challenging and requires carefully designed policy measures. These should be based on a sound analysis of the sectoral and regional contexts in which technological trajectories emerge. In light of these considerations, this essay aims to provide insights on how Europe can try to address the sketched challenges and which strategies will help European locations and firms to be competitive under the circumstances described above.

1.2 Theoretical and conceptual considerations

General Purpose Technology

More than twenty years ago, Bresnahan and Trajtenberg (1995) created the term General Purpose Technology (GPT). They described emerging technologies with an enormous economic impact, as "Whole eras of technical progress and economic growth appear to be driven by a few key technologies, which we call General Purpose Technologies (GPTs). Thus the steam engine and the electric motor may have played such a role in the past, whereas semiconductors and computers may be doing as much in our era. GPT's are characterized by pervasiveness (they are used as inputs by many downstream sectors), inherent potential for technical improvements, and innovational complementarities', meaning that the productivity of R&D in downstream sectors increases as a consequence of innovation in the GPT. Thus, as GPT's improve they spread throughout the economy, bringing about generalized productivity gains."

GPT's are enabling technologies, as they offer a generic function which can be used productively in a wide range of application fields. They arise when innovations are characterized by three features: pervasiveness, technological dynamism (scope for improvement) and innovation spawning as well as innovational complementarities, i.e. interdependent innovation processes along the value creation chain. When performance and quality of the GPT is improved, downstream application sectors can significantly benefit and are incentivized to improve their own technology as this makes new products and markets available. R&D activities in both the GPT and downstream sectors along the whole value chain are likely to be cumulative and reinforcing (Bresnahan, Trajtenberg 1995). Profits in both areas are interdependent. Commercialization of downstream products will raise the demand for further improved GPT. In doing so, GPTs and the pervasion of downstream sectors is driven by repeating feedback loops. The result is a disruption of more and more existing value chains and the continuous penetration of technological trajectories in traditional sectors. Finally, on an aggregate level, the emergence of a GPT affects overall growth (Ott, Teichert 2011). This is why European Innovation Policy focusses on GPTs as potential drivers for economic growth in existing sectors.

Spatiality in innovation and why regions matter

However, a major challenge for each policy intervention is the question on how to choose policy funding priorities. One potential answer has been given within the "Smart Specialization" concept. The Knowledge for Growth Expert Group proposed, being alerted by the emergence of a "transatlantic productivity gap," that European industries suffer from a limited ability to adopt and adapt to new technology and innovations emerging from other sectors (Foray et al. 2009; McCann/Ortega-Argilés 2013). As a conclusion, it is argued that the EU should prioritize the alignment of actions and interventions so as to maximize the opportunities for fostering entrepreneurial search processes. To this end a "smart specialization" agenda is proposed. The main argument is that scale-effects and knowledge networks across heterogeneous, but related domains should be exploited more efficiently. The potential for diversification into related sectors, activities or technologies should be leveraged in order to enhance innovation-driven economic development.

Nonetheless, one highlighted and often empirically proven aspect of cutting edge innovation is the spatially bounded nature of innovation activities and processes. Regional and economic contexts shape innovation processes and provide the circumstances under which innovation activities take place. The main argument is that spatial proximity, though not being sufficient, enables face-to-face contacts and the exchange of advanced and complex implicit knowledge (e.g. Boschma 2005). This in turn facilitates creativity as well as the evolution of innovation and is the basic argument on why industries tend to cluster and some regions are more innovative than others (e.g. Feldman 1994). Two different driving forces of agglomeration advantages are discussed in this context. Those relate to the Mashall-Jacobs controversy, or in other words: specialization vs. diversification.

Firstly, Marshall (1890) pointed to the productivity-enhancing effect of spatial proximity leading to location externalities. Corresponding knowledge as well as spillovers between various actors, however, refer to specialization and are industry-specific. Recent research showed that tacit knowledge and spatially bound knowledge spillovers encourage local collective learning processes. Particularly, specialization and concentration of an industry in a region stimulates R&D collaboration, exchange of skilled workers and a multitude of different spillover mechanisms (e.g. Maskell/Malmberg 1999; Audretsch/Feldman 2004).

Secondly, a contrary line of argumentation is that too much specialization might lead to lock-in effects hindering the emergence of new technological trajectories. The reason for this is that only complementary, but mainly homogeneous knowledge is exchanged. As a consequence, Jacobs (1969) argues in favor of city-specific externalities and suggests that the diversity of economic structure fosters the recombination and diffusion of ideas. In conclusion, differentiated knowledge bases create a greater variety of knowledge spillovers and innovations created in one industry are more likely to be applied and/or further developed in other industries.

In sum, innovation activities, particularly in knowledge-intensive industries, tend to cluster and empirical evidence shows that specialized economic structures along entire value chains tend to be more innovative. At the same time cross-fertilization between essentially different and (so far) unrelated, but at least to some extent related technologies and sectors helps firms to benefit from new technological possibilities, ideas and knowledge spillovers. These arguments closely connect to the related variety discussion (Frenken et al. 2007; Boschma et al. 2012) and are resembled in the smart specialization approach (McCann/Ortega-Argilés 2011). Accordingly, the smart specialization agenda, as a main element in Europe's re-industrialization strategy, is not directed towards sectoral specialization. It rather aims at fostering diversification around a core set of activities and themes. As shown above, these arguments are closely linked to the spatial dimension in knowledge and technology transfer. Therefore, though it originated from spatial thinking on knowledge spillovers and R&D, the smart specialization concept is strongly linked to the regional context and focuses on the embeddedness of activities and actors in a region, the potential for exploiting related variety as well as the importance of developing connectivity both inter-regionally and intra-regionally between firms and institutions (McCann/Ortega-Arigilés 2013).

Smart Specialization

The smart specialization concept is also related to the dynamic capabilities approach in its original as well as regional version (see von Tunzelmann 2009). It highlights the need for firms to learn and accumulate new knowledge but simultaneously acknowledges the integration of behavioral, social and economic factors into a specific set of outcomes. Capabilities are seen as the result of adaptive learning processes. In other words, highly qualified human resources are not a capability per se, but they constitute a resource that, through learning, can become a source of technological capabilities for the firm or the system as a whole. Human resources and cooperative innovation linkages are amongst others considered determinants of a firm's technological capabilities (Iammarino/McCann 2009). In addition, the 'open innovation' model (Chesbrough, 2003; Laursen and Salter, 2006) recognized that innovative firms draw knowledge from a variety of external sources and linkages, integrating them into their own routines and learning processes, thus achieving more advanced technological capabilities. However, as shown above, knowledge exchange, interaction and innovation networks exhibit a certain spatial bias. Thus, in their collective dimension, firm-level capabilities can be highly localized, leading to system capabilities, i.e. they refer to a specific spatial and industrial setting. In doing so, the latest applications of the capabilities framework to regional innovation systems have emphasized that regions can be considered as spatial congregations of suppliers, producers, consumers, etc., each with their own unique level of capabilities (von Tunzelmann, 2009). Shifting the logic from mere co-location to co-evolution, it is argued that for a region to be progressive, its capabilities need to be interactive – i.e. those of its producers, suppliers and customers need to be able to cope with the continuous change of the actors' needs and abilities. However, regional capabilities cannot be considered merely the sum of individual firm-level capabilities (von Tunzelmann, 2009). A firm's technological capabilities and growth additionally depend on many external elements and the constitution of its surrounding innovation system (e.g. Cooke et al., 1997).

Taken together, the smart specialization approach encourages regions to build their innovation strategies around both the existing structure and the related potential diversification opportunities available. In doing so, it focuses on existing local and firm capabilities, the enhancement of local linkages and the development of new pathways for ideas and entrepreneurial actions to take place. It furthermore stresses the importance of information and evidence-based decision making. Therefore, the development of national as well as regional strategies requires a profound knowledge of regions' and firms' capabilities and assets as well as local economic structures. In order to clarify its strengths, weaknesses, opportunities and threats, substantial baseline indicators and analyses regarding a region's economic and institutional profile, particularly the region's knowledge-related innovation and entrepreneurial activities, are needed (McCann/Ortega-Argilés 2013).

Summary and reminder

The key messages from these brief theoretical and conceptual considerations are twofold. Firstly, the microelectronics industry as a GPT offers huge potential for innovation in related sectors. Therefore, it constitutes a strategically important element for sectoral innovation within Europe. Secondly, it is likely that its application context will depend on the characteristics and relative strength of different regions in Europe in the relevant related application sectors.

Having these considerations in mind, this essay aims to provide an overview on the specific characteristics of the technology, their economic implications, the current situation in the microelectronics industry from a European perspective and finally it aims to derive recommendations on how Europe can support and strengthen its position in the microelectronics related industries.

In doing so, the essay pursues the following research questions:

1. What exactly makes microelectronics a general purpose technology and what are its crucial characteristics?
2. What is the current European situation in the microelectronics industry?
3. What are the comparative weaknesses and strength of the European microelectronics industry?
4. How can Europe successfully adjust to current dynamics in microelectronics and how can industrial policy effectively support?

Firstly, a definition and an overview on the value chain in microelectronics and the specific role of semiconductor production will be given. The focus lies on characteristics, related economic aspects and future perspectives of the technology. The second part analyzes and presents the competitive situation in the global value chain from a European perspective. Finally, the last part of this essay develops policy recommendations.

2 Microelectronics: Technological basics and perspectives

2.1 Semiconductors: Technological basics

This section will provide a brief overview on the technological basics behind microelectronics. In doing so, it aims at conveying a basic understanding of the specific characteristics which make microelectronics a special case. Semiconductors and their production are the technological basis of microelectronics. Remarkable dynamics that took place in semiconductor evolution in the last centuries had an extreme impact on the role that microelectronics play in today's economy.

Semiconductors: The foundation of microelectronic technology

Two groundbreaking inventions led to the evolution of the microelectronic technology. Firstly, in 1947 the Bell Laboratories announced the creation of the first transistor. Secondly, Texas Instruments (1958) as well as Fairchild (1961) invented the integrated circuit (also referred to as IC, chip or microchip). This consists of transistors, resistors, capacitors and inductors, which are fully integrated in or on a single piece of semiconductor substrate. They are connected by conductive wires or traces enabling electric signals to flow and allowing various simple and complex operations to be performed: signals can be amplified, computations can be performed, and data can be moved from one place to another. Put simply, these inventions constituted the origins and paved the ground for the emergence of the semiconductor industry in the US (Danish Technological Institute 2012). In being the core of the technology, ICs fulfill different functions and are used in different applications. A basic distinction differentiates four basic semiconductor-based components (Fan 2006; Arden et al. 2010):

1. Memory chips: Components that function as part of the computer memory (e.g. ROM, RAM, DRAM).
2. Microprocessors and Microcontrollers: Components that play a role in information processing.
3. Application specified chips: Electronic chips being manufactured flexibly and individually for a broad range of customers and purposes.
4. System solutions: System architecture that brings the above functions together in systems of chips or even a functional chip including a complete system (Systems on a chip).

Semiconductor production involves a series of highly complex and knowledge-intensive production steps. Thus, it requires advanced technological knowledge on materials, production technology as well as processes. The basic steps and procedures for the fabrication of semiconductors are described in the following.

Main steps in semiconductor production

Commonly, the production of semiconductor components is roughly broken down into four main steps:

1. Chip design and raw waver production: These two steps lay the foundation for semiconductor production. Here the necessary materials and tools are manufactured, i.e. that the integrated circuit is planned and the raw wafers are created from semiconductor material, such as silicon crystal. The wafer is a thin slice of formed highly

pure (99.9999 percent purity) single crystalline materials. Its fabrication involves many complex steps and the use of several types of raw material. Essentially, suitable sands are melted down and used as the basic material to fabricate a pure silicon cylinder, called an ingot. Using a diamond saw, this ingot is cut into very thin slices, called wafers. These are etched, cleaned and a chemical-mechanical process polishes them in order to smooth out any surface irregularities, and to make the wafer flat enough to support optical photolithography. Finally, the wafers undergo a final test in order to ensure its conformance with customer specifications for flatness, thickness, resistivity and type.

2. Front-end processing: In this step the circuits are implemented and sealed. Based on the chip design, the wafers are processed into small pieces of silicon. Such a small piece is called die and will, once packaged, become an integrated circuit. Until this point, modern chips require over 300 processing steps. These are conducted in a sterile environment and include a complex process of ion implantation, etching, deposition of various materials and photolithographic patterning.
3. Back-end operations: Here the semiconductor devices are assembled and the resulting chip is tested. These operations have long been regarded as the less attractive and technologically less sophisticated part of the production process. Therefore there has been a tendency to outsource them. Recently though they are receiving increasing attention, since this is the production step where multiple dies are integrated in a system, which is part of the technological advancements behind the Internet of Things (IoT).
4. The users: In a final step the semiconductor devices are further used and distributed by sub-system assemblers or end-equipment manufacturers.

2.2 Economics and future trends in semiconductor industry

Besides the technological basics, one specificity regarding semiconductors and microelectronics are the dynamics under which technological evolution takes place.

Special dynamics in semiconductor evolution: Costs and performance

The semiconductor industry has recorded impressive achievements since 1965, when Gordon Moore, the co-founder of Intel, made his observation that every second year, a transistor would become 50 percent the size of what it was two years ago. As a consequence the number of transistors on integrated circuits doubles within two years. Accordingly, this phenomenon was called "Moore's law". Its technological basis is shrinking transistor sizes, enabled by advanced fabrication processes, leading to an exponential down-scaling of microelectronic devices. As a byproduct, this resulted in simultaneous cost-reductions, while the performance of semiconductor components improved significantly. They reach higher degrees of compactness, their operation requires less current, resulting in reduced heat development as well as power consumption. At the same time they generate an exponentially higher speed, due to the greater quantity of transistors on one chip (Van der Velde et al. 2013).

Taken together, during the last four decades there has been an ongoing trend to constantly reduce the production costs per unit and to increase the performance of micro-electronic components. In doing so, the semiconductor industry puts huge efforts into innovation and R&D activities, making it one of the most R&D-intensive industries (EUROPEAN COMMISSION 2013). Thus, scaling of transistors enables a better performance and cost ratio of products. This is driven by constant technological innovation and corresponding investments into R&D, driven by the industry's "International Technological Roadmaps"[1] which describe the technological progress required for the continuation of "Moore's Law". These continuing efforts to uphold the trend of exponential technological development and to generate "More Moore" have been the key driver for the microelectronic industry over the last centuries. This consequentially causes exponential growth of the semiconductor market. In doing so, a virtuous circle drove the semiconductor industry's impressive growth (Arden et al. 2010).

Whether this trend is going to uphold or not, depends on two crucial areas of technological innovation (Bauer et al. 2013):

1. Lithography tools: Traditional lithography technologies reached their limit. Up until now, further levels of down-scaling have been made available by the introduction of double and multi-patterning technologies. This involves overlaying several lithography steps and enables a higher feature density. Multi-patterning was first used for 32nm and 28nm nodes and could enable the industry to scale nodes below 14nm. Nonetheless, these production processes are associated with exploding per-layer costs as well as significantly rising levels of complexity, making the next generations of chip production economically less feasible for mass-production.[2]

   A new technological innovation that could help to overcome these limitations is the extreme-ultraviolet (EUV) lithography. This uses new light sources with significantly shorter wave-lengths and could therefore help to produce even smaller structures with fewer steps.[3] This would help to reduce the production costs compared to multi-patterning. Due to unresolved technological issues, this technology is not ready to be executed yet. While some industry experts believe that it is likely to become feasible within five years, others are rather skeptical in this regard.

2. Increasing wafer sizes: Larger semiconductor wafer sizes are another source for further productivity improvements. They promise significant cost savings in IC production. Cutting-edge production grew from 150mm wafers in the early 1980s to 300mm wafers, nowadays. In doing so, the industry has made significant productivity improvements by transitioning to larger wafer sizes. The next step that the industry is working on is the transition to 450mm wafer production. This would increase the produced amount of ICs per wafer by 125 percent, compared to the current 300mm wafer production. By raising the numbers per wafer, labor costs could be reduced and higher yields would be gained. At the same time equipment cost would increase. According to Bauer et al. (2013), a full scale 450mm production fabrication plant would cost between $10 billion and $15 billion. Only few industrial players have the financial

[1] http://www.itrs.net/about.html

[2] A scaling from 32nm (using "old" argan fluid immersion lithography) to 22nm (using multipatterning lithography) would raise the cost per layer by estimated 50percent (Bauer et al. 2013).

[3] Industry experts expect that EUV will reduce the costs per layer by round about 35percent, because double-patterning requires significantly more steps (ca. 30) per layer, while EUV is likely to need just ten.

resources to afford such investments. Yet, the industry already explores and prepares for the transition. Intel, for example, invested in 450mm development by ASML and the Global 450 Consortium[4] build a test facility in New York.

In sum, due to the strong competition and the fast technological dynamics, the production in semiconductor industry has become more and more capital-intensive. The reason is that continuing node progression and the according size reduction lead to increasing complexity in semiconductor production and call for new and advanced manufacturing processes as well as technologies. Scaling requires a completely new design of the chip itself, the manufacturing process and even the foundry. Table 1 exemplifies the interdependency between node size and cost progression since 2001. It is obvious that each scaling step led to significantly higher costs resulting from the construction of a new foundry, process development and new chip design.

Table 1: Costs (in $mn) related to scaling in semiconductor production

	2001	2004	2006	2008	2010	2012	CAGR '01-'12
Node size	130 nm	90 nm	65 nm	45 nm	32 nm	22 nm	
Foundry cost	1,450	1,800	2,500	4,000	4,850	6,700	0,15
Process development cost	250	310	400	600	900	1,300	0,16
Chip design cost	15	24	34	60	100	150	0,23

Source: Numbers represent estimations derived from Sonderman 2011; own calculations

To give an example, a new foundry that is suitable for state-of-the-art chip production in 2012 (22nm nodes) required 4.6 times the level of investment than 2001 (130nm nodes). The compound annual growth rate (CAGR) for investments in chip factories (foundries), process development as well as chip design costs increased significantly since 2001. This demonstrates the exploding cost dimension. Due to rising investments required for leading edge lithography and the complexity of multi-patterning processes, new foundries are becoming ever-more expensive. This trend of increasing costs, known as "Rock's Law", is the flipside of "Moore's Law". It is named after Arthur Rock, a Silicon Valley venture capitalist, who noted that the cost of a semiconductor chip fabrication plant doubles about every four years (Allen 2012). Accordingly, Bauer et al. (2013) estimate that the next generation of state-of-the art foundries will cost ca. $10bn or even more. In addition, costs for fabrication, process development and chip design will rise by 40 to 50 percent.

Overall, each technological step opens new technological as well as economic opportunities, but at the same time it is related to rising costs. Economies of scale become particularly important at this point, i.e. the higher investments into production infrastructure are to be amortized by higher numbers of dies produced per wafer. This is why wafer sizes tend to increase at lower nodes. In doing so, more dies can be retained from one wafer and the capital expenditures per die are reduced. As a result savings become more prominent for lower nodes and therefore even rising investments are likely to amortize. However, only few firms will be able to make the needed future investments in these new production lines, and whether or not they amortize will also depend on the availability of a technological solution in lithography tools.

[4] http://www.g450c.org/ (Online: 18.03.2015)

2.3 Essentials and future challenges from a technological perspective

Semiconductors are the technological basis for microelectronic products and these are a source for efficiency as well as productivity gains in an even larger number of industries. Therefore, the technology and its support are considered strategically important for industrial policy. Be that as it may, the technology and semiconductor products exhibit some peculiarities and obviously follow a set of specific rules. In doing so, the most appealing and at the same time challenging characteristic is it disposition towards extreme growth and fast dynamics. The industry invests many resources into research and development, being constantly on the search for new technological solutions and progress. Nevertheless, a slowing down of this process can currently be observed and there are some indications that this will continue. Whether or not the industry is going to catch up with its former pace depends on its ability to surpass technological barriers and address the related economic bottlenecks. The main argument here is that costs, related to continuing node progression, including sunk costs resulting from fast outdating technologies, are increasing significantly. This might make the production of new generations of semiconductors unprofitable and economic conditions might cause the abolishment of "Moore's Law". Two basic scenarios are imaginable here:

Firstly, the semiconductor industry, condemned to growth, still heavily prepares the transition to the next generation of semiconductor technology and production. Even though some aspects of the microelectronics industry remain uncertain, it is clear that only few locations would/will be able to build and operate future state-of-the-art production sites. This is mainly due to the high investment costs, but also overcapacities which are a likely result. Furthermore, as the amounts of chips produced per plant have to rise in order to reach sufficient economies of scale, overproduction necessarily constitutes a limit. The demand for microelectronic products is not unlimited. Taken together, under the scenario of ongoing node progression, future cutting-edge and state-of-the-art production is likely to take place at only a few selected locations (Bauer et al. 2013; Danish Technological Institute 2012).

Secondly, Moore's law ends, or at least staggers, over a longer period. Here a consolidation of the industry is likely to take place. This is due to the fact that existing players, especially foundries, are exposed to cost pressure and try to secure scale effects. Furthermore, this would enable lagging-edge players to catch up and enter competition with established firms (Bauer et al. 2013). Diversification and differentiation would only be possible over niche solutions, e.g. specific chip designs, specialized system solutions or new software developments.

Either way, a consolidation of the chip making industry is likely to take place. From a European perspective, the subsequent question is: what is the current situation in the microelectronics industry and how is this going to change, in the light of these described developments? This is discussed in the next section.

3 The current situation in global microelectronics industry

3.1 The fragmentation of the global semiconductor value chain

Currently the semiconductor value chain is characterized by strong fragmentation as well as internationalization. The growing complexity of its technological basis had a strong effect on the whole microelectronics industry. In early stages, the semiconductor industry was dominated by Integrated Device Manufactures (IDMs) integrating the whole value chain into their business model. Oftentimes they included not only the chip-production itself, but also the production of manufacturing equipment and materials at one end as well as electronic products and services on the other. Nowadays, due to extensive vertical disintegration, the production model has changed completely. It evolved from a linear chain to a networked model (ESIA 2008).

In the early 1980s, the fabrication segment started to separate from the design element and the first fabless firms emerged. The development of Electronic Design Automation (EDA) tools in 1981 led to the formation of EDA companies and IDMs began to outsource parts of their design activities and designs to so-called "design houses". These in turn, as the demand from IDMs was not steady, started to develop their own products (forming the first fabless companies) and began to mandate the first foundries, which were laboratories or small companies, with the production of ICs. In the 1990s, the company TSMC (Taiwan Semiconductor Manufacturing Company) played a central role in the evolution of the semiconductor value chain. It acted as a pioneer in the foundry business and still remains the leader of pure-play foundries with over 50 percent market share (IC Insights 2014). Furthermore, it is one of the main drivers for the development of the semiconductor industry in Taiwan and it dominates a number of IT equipment manufacturing sectors. Moreover, the emergence of the system-on-chip methodology led to a further disintegration of the design part of the value chain into EDA and Intellectual Property (IP) providers and design houses (Danish Technological Institute 2012).

In sum, during the last decade the long-term trend in the task fragmentation of the semiconductor value chain has continued and was caused by five main reasons (Danish Technological Institute 2012):

- cost reductions by moving production to 'low cost' labor 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 slow pace of company concentration in the semiconductor industry;
- the increasing costs of building and equipping foundries.

The following section will provide an empirical overview on how these developments have changed the global distribution of the microelectronics industry and on how Europe is positioned within the industry.

3.2 Europe in the semiconductor industry

This section aims to show how much of the microelectronics industry and value chain remained in Europe. In doing so, it gives an overview on the geographical dispersion of activities related to technology, trade and the key corporate players in the field from a European perspective.

Generation of technological knowledge in microelectronics measured by patents

Figure 1 displays the shares of specialization in international patent applications in microelectronics by the three major world regions (Europe, North America, East Asia)[5]. It shows that, since 2000, East Asia outpaced the rest of the world regarding the share of internationally filed patents. Europe and North America lost significant shares over time. In 2011, over 50 percent of the global patent output in micro- and nanoelectronics originated from East Asian countries. North America, starting from 37 percent, nowadays, accounts for ca. 20 percent. Europe's share declinedfrom 24 percent in 2010 to 16 percent in 2011. Taking patents as an indicator for a country's performance in the production of new technological knowledge (van der Velde et al. 2014), it becomes obvious that East Asia has overtaken Europe and North America regarding its ability to produce technological knowledge relevant for industrial application. Particularly Europe ranks last among the three largest producers of technological knowledge in micro- and nanotechnologies.

Figure 1 further complements the specialization[6]. It relates the significance of micro- and nanotechnology in the country considered to the average significance of that technology in all countries. This indicator tells whether a country puts more or less focus on this technology than other countries do (van der Velde et al. 2014). Thus, it indicates the relevance of technological innovation in this particular area in relation to other innovation activities. It can be seen that East Asia is highly specialized in technological innovation in microelectronics, while Europe is less focused on this technology than other countries. North America seems to undergo a slight shift from giving micro- and nanotechnology neither a particularly high nor low relevance to a relatively lower focus.

Taken together, these figures indicate an innovation gap for Europe as measured by patenting activities, at least in semiconductors and directly related devices.[7] Furthermore, they show that Europe seems to put less emphasis on technological development in this area than others do.

Digging deeper into the country-level dynamics, by looking at the five countries with highest shares in microelectronics patenting in the world compared to those in Europe (c.f. Figure 2), we find that Japan dominates technological innovation in terms of international patent filings, accounting for over 35 percent of the world market share. The US saw a significant decline from over 35 to under 20 percent, but still remains second largest producer of technological knowledge. The Republic of Korea and China have been catching up, with Korea equaling the world market share of Germany. Taiwan remains below one percent over the observation period. Germany is by far the dominant country in Europe. However, it lost shares in the world market,

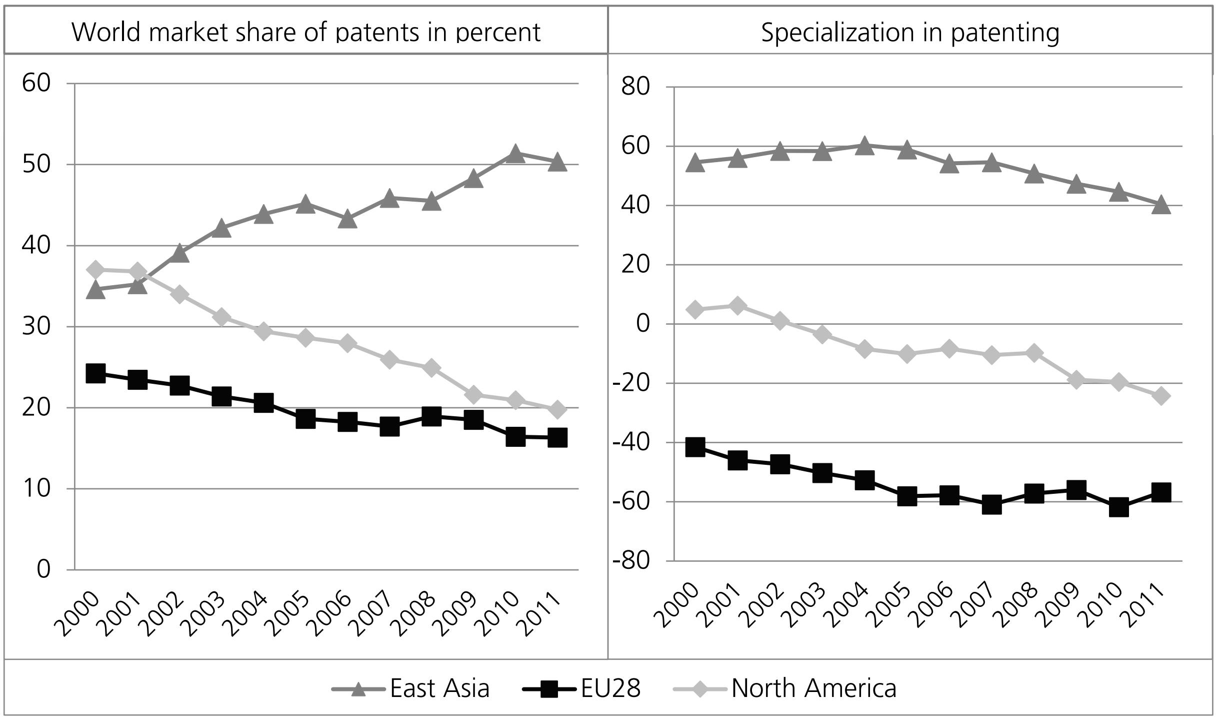
[5] East Asia = Japan, China, South-Korea, Singapore, Taiwan; EU = Europe 28; North America = Canada, US

[6] In this case, the indicator refers to all 44 countries listed in the KETs Observatory (see van der Velde et al. 2014).

7 Micro- and nanoelectronics covers new technologies related to semiconductors, piezo-electrics and nanoelectronics identified by IPC classes as defined by van der Velde et al. 2013 (KETS Observatory): Semiconductor materials- Sensor-, Actuator-, RF-, Photonics based communication-, energy storage-, energy harvesting- and micro computing- technologies, computer memory, alternative computing, MEMS and NEMS, power electronics, Passive electronic materials, hardware architectures.

starting with ca. 13 percent in 2000, nowadays making up for around eight percent of the world market share. France accounts for ca. four percent while the UK, the Netherlands and Switzerland range between one and two percent.

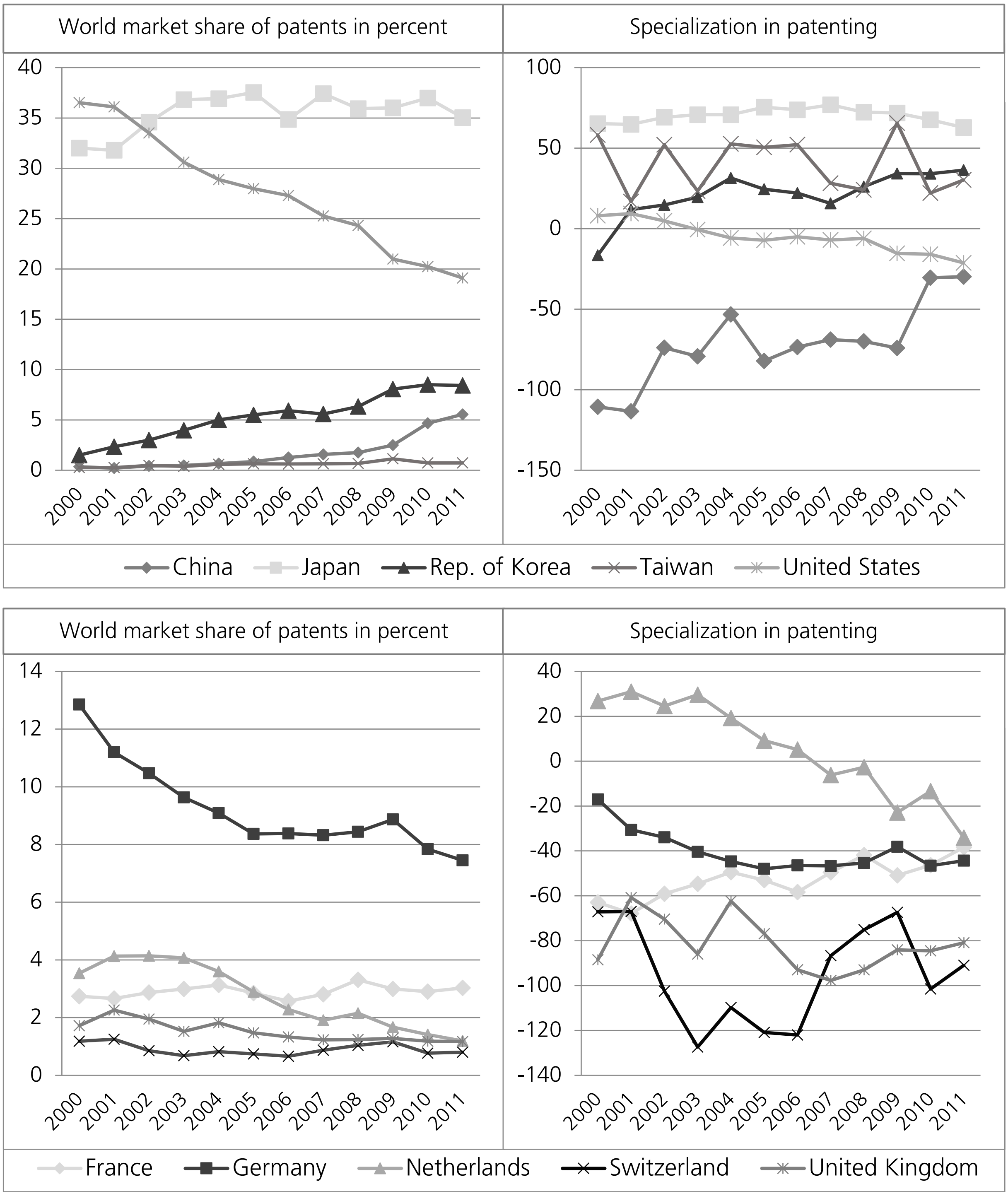
Figure 1: International patent applications by world region, EPO/PCT



Source: Own compilation, based on data provided by the KETs Observatory (https://webgate.ec.europa.eu/ketsobservatory/kets-deployment/technology/timeseries/mne (Online: 19.01.2015)

Taking the technological specialization for the considered countries into account, it becomes obvious that Japan maintained a strong focus on microelectronics over the period of observation. Of coruse, technological innovations in this technological area are of high importance to the country. Interestingly, though not reflected in terms of market shares (as shown above), microelectronics have a comparatively strong position in technological innovation in Taiwan. China constantly increased the focus in this particular area in relation to the other countries, but is still exhibiting a negative specialization, i.e. other technologies have a higher weight (in relation to the rest of the world). For the US microelectronics are of average, however, slightly decreasing weight in technological innovation activities. The European countries currently all exhibit a negative specialization. Particularly, the Netherlands display a downwards trend regarding the relevance of microelectronics in its technology-related innovation activities. The same is true for Germany, however starting from a lower level. The UK and Switzerland display, besides having a strong negative specialization, less constant curves. On average the latter shows a negative trend, while the first is rather stable. The only European country with a positive trend is France.

Figure 2: International patent applications - TOP5 RoW vs EU, EPO/PCT



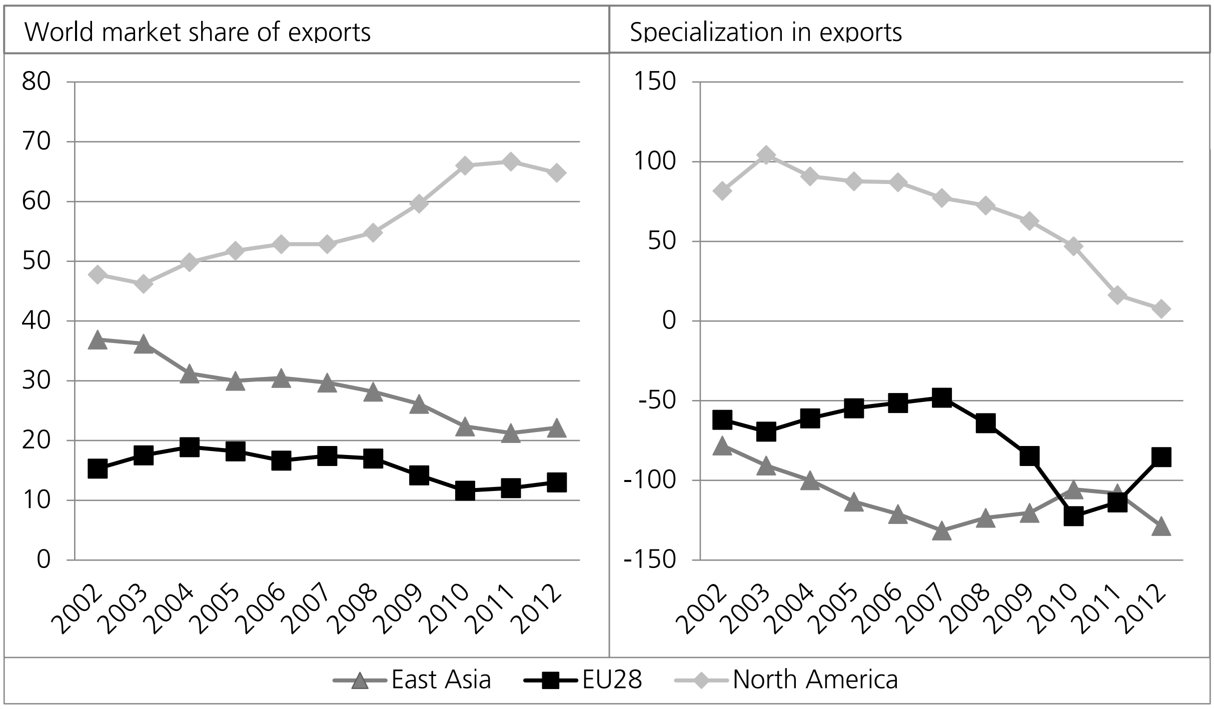
Source: Own compilation, based on data provided by the KETs Observatory (https://webgate.ec.europa.eu/ketsobservatory/kets-deployment/technology/timeseries/mne (Online: 19.01.2015)

Overall, we can conclude that it is mainly Japan and the US, the latter with decreasing statistical importance, that are accountable for the main share of technological innovation activities in microelectronics (at least as measured by patents). Other Asian countries are catching up in overall shares, putting a stronger focus on this area than European countries do. The latter is not only loosing market shares, but also placing less emphasis on technological innovation in this area.

Europe's position in global trade of semiconductor products

Besides accounting for input of technological knowledge, the following remarks aim to give an impression on the role that Europe plays in global trade as measured by exports. Figure 3 shows the market shares of the three considered regions in international trade. It therefore indicates how much a country contributes to the total exports of all countries.[8] The numbers closely resemble the picture gained in the patent analysis. The message here is that East Asia gained the highest share in world market exports and steadily extended it from 48 to over 65 percent. However, East Asia and Europe are not specialized in microelectronics as Northern American countries are. North America exhibits a stronger export specialization in microelectronic products.

Figure 3: *Exports by world region, EPO/PCT*

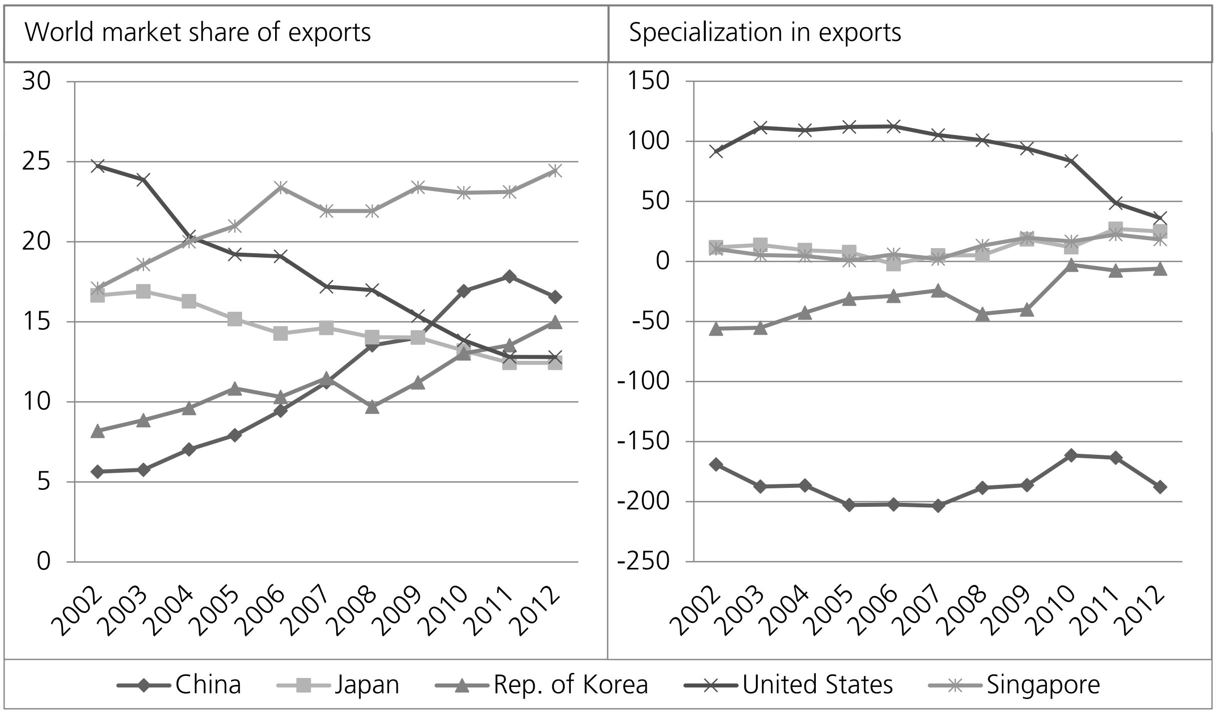


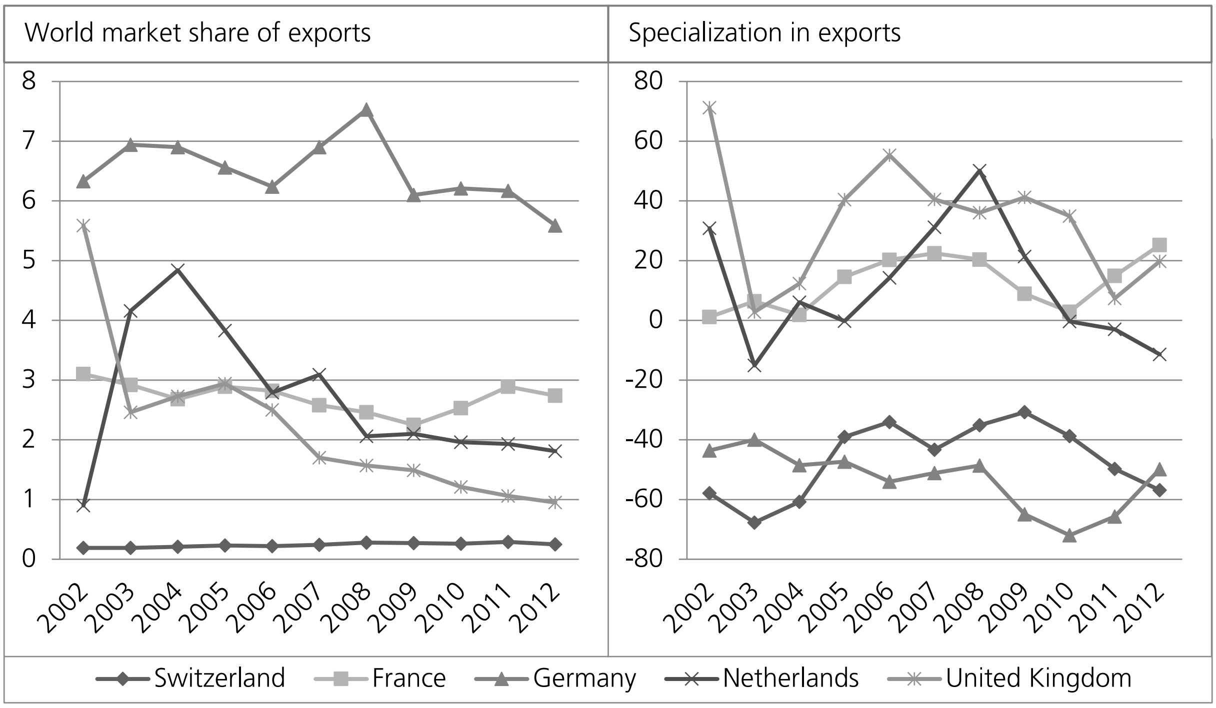
Source: Own compilation, based on data provided by the KETs Observatory (https://webgate.ec.europa.eu/ketsobservatory/kets-deployment/technology/timeseries/mne (Online: 19.01.2015)

Again, Figure 4 provides a deeper understanding of the dynamics taking place on country level. It displays the five largest non-European as well as European exporters of microelectronic products, as measured by shares of worldwide exports. Interestingly, Singapore appears as the largest exporter of microelectronic components, although it does not appear among the large producers of technological knowledge (c.f. Figure 2). The US lost their leading position of 2002 and ranked fourth in 2012.

Figure 4: *Exports by TOP5 RoW countries, EPO/PCT*

[8] 44 countries considered: China and Hong Kong are regarded as one country. For this purpose, total exports and imports of China (including Hong Kong) are cleaned by bilateral (intra-regional) trade flows. Taiwan is missing in trade analysis, because the country is not covered by international trade databases (UN Comtrade, OECD) (van der Velde et al. 2014).





Source: Own compilation, based on data provided by the KETs Observatory (https://webgate.ec.europa.eu/ketsobservatory/kets-deployment/technology/timeseries/mne (Online: 19.01.2015)

Besides Singapore, China and Korea underwent an impressive catching-up progress and each account for more than 15 percent of the world share in exports. Japan declined, but still accounts for ca. twelve percent. In Europe, again Germany appears as the largest exporter, however, revealing a significant and constantly rising gap to the Asian countries, particularly in recent years. The Netherlands as well as the UK both experienced a significant downturn of their shares; both coming from round about five percent, the UK share fell to two percent in 2003 and the Netherlands share fell to approximately three percent between 2004 and 2006. France and Switzerland maintained their shares at three and one percent, respectively.

Now looking at the export specialization, it is found that the role of microelectronics in export portfolios is obviously heterogeneous. For the US, while exhibiting positive values, we observe a declining relevance. Singapore as well as Japan show only slightly positive values, which indicates that microelectronics play an average role for these countries. They are not specialized (neither positive nor negative). The Republic of Korea developed in a similar direction (coming from negative values), while China exhibits a strong negative specialization. This explains the strong negative effect for East Asia observed above. For France, the UK and the Netherlands, the specialization values vary strongly over time und range between a specialization as well as a neutral position. Switzerland and Germany are negatively specialized.

In sum, these numbers provide further evidence for the fact that East Asia dominates the world market not only regarding the production of technological knowledge, but also the export of microelectronic devices and components. Furthermore, East Asia exhibits a strong positive trend, while Europe and the US display declining shares. However, some European countries have a relatively strong emphasis on exports in this area. This might cause reason for concern, since, as seen above, innovation activities in these countries are comparatively low, while their export activities exhibit a relatively strong focus on microelectronics. At the same time, the amount of exports is not necessarily related to the technological knowledge base. This indicates that some countries act as rather pure manufacturing spots, while others are either trade hubs or have a focus on knowledge production and manufacturing of advanced products.

Europe's corporate basis in terms of sales of semiconductor related products and R&D

The last remarks made clear that Asian countries outperform the US and Europe in both knowledge production as well as exports. Europe lost ground especially. This is also expressed in terms of sales of IC-related products. Table 2 shows that only 13 foundries account for 91 percent of the total foundry sales in 2013. The headquarters are mainly located in East Asia (five in Taiwan; three in South Korea; two in China). Two are located in the US and one in Israel. None are located in Europe.

A different, no less interesting picture emerges when the top R&D spending companies are taken into account (c.f. Table 3). Obviously, five (US-) American corporations belong to those spending the largest amounts of R&D, Intel being far ahead, three of them with very high R&D-intensities (Intel: 22 percent; Qualcomm 20 percent; Broadcom 30 percent). Interestingly only two Japanese companies (Toshiba, Renesas) are among the TOP10 R&D spenders. South Korea (Samsung), Taiwan (TSMC) and Europe (ST) are each represented by one country. Together with the finding from above, one can conclude that US firms are heavily engaged in R&D. At the same time, production largely takes place in East Asia. This is further confirmed by Figure 5, showing that particularly US, but also South Korean firms outsourced parts of their 300mm wafer production. Interestingly, when considering only 300mm Wafer production, European locations have a higher share of the world production than US locations. Nonetheless, this picture changes when the headquarters of the firms are accounted for.

Table 2: Major 2013 IC Foundries (Pure-Play and IDM)

Rank	Company	Pure-Play	IDM	Location	2013 Sales ($M)
1	TSMC	X		Taiwan	19,850
2	GlobalFoundries	X		US	4,261
3	UMC	X		Taiwan	3,959
4	Samsung		X	South Korea	3,950
5	SMIC	X		China	1,973
6	Powerchip	X		Taiwan	1,175
7	Vanguard	X		Taiwan	713
8	Huahong Grace	X		China	710
9	Dongbu	X		South Korea	570
10	TowerJazz	X		Israel	509
11	IBM		X	US	485
12	MagnaChip		X	South Korea	411
13	WIN	X		Taiwan	354
Top 13 Total					**38,920**
Top 13 Share					**91%**
Other Foundry					**3,920**
Total Foundry					**42,840**

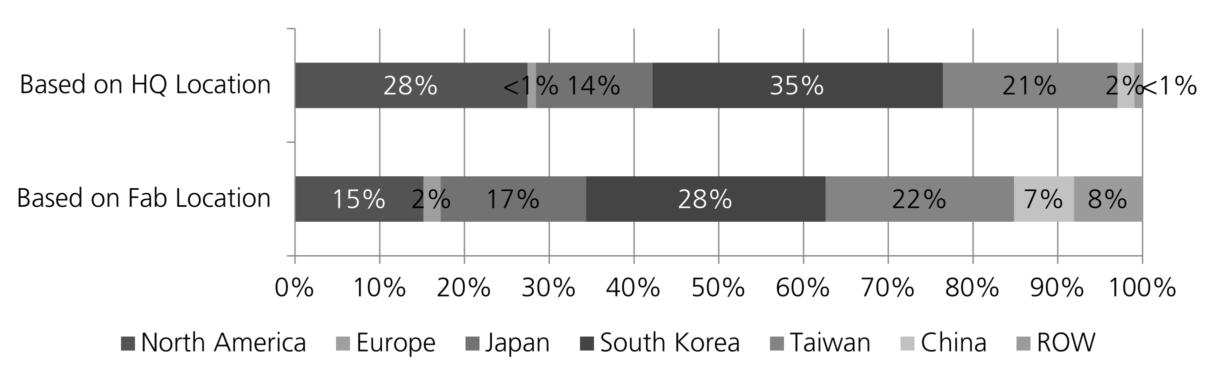
IC Insights 2014a

Table 3: 2014 Top Semiconductor R&D Spenders

Rank	Company	Region	IDM	Fabless	Foundry	2014		
						Semi Sales ($M)	R&D Exp. ($M)	R&D/Sales
1	Intel	Americas	X			51,400	11,537	22.4%
2	Qualcomm	Americas		X		19,291	5,501	28.5%
3	Samsung	Asia-Pac.	X			37,810	2,965	7.8%
4	Broadcom	Americas		X		8,428	2,373	28.2%
5	TSMC	Asia-Pac.			X	24,976	1,874	7.5%
6	Toshiba	Japan	X			11,040	1,820	16.5%
7	ST	Europe	X			7,384	1,520	20.6%
8	Micron	Americas	X			16,814	1,430	8.5%
9	MediaTek + Mstar	Asia-Pac.		X		7,032	1,430	20.3%
10	Nvidia	Americas		X		4,348	1,362	31.3%
Top 10 Total						**188,523**	**31,812**	**16.9%**

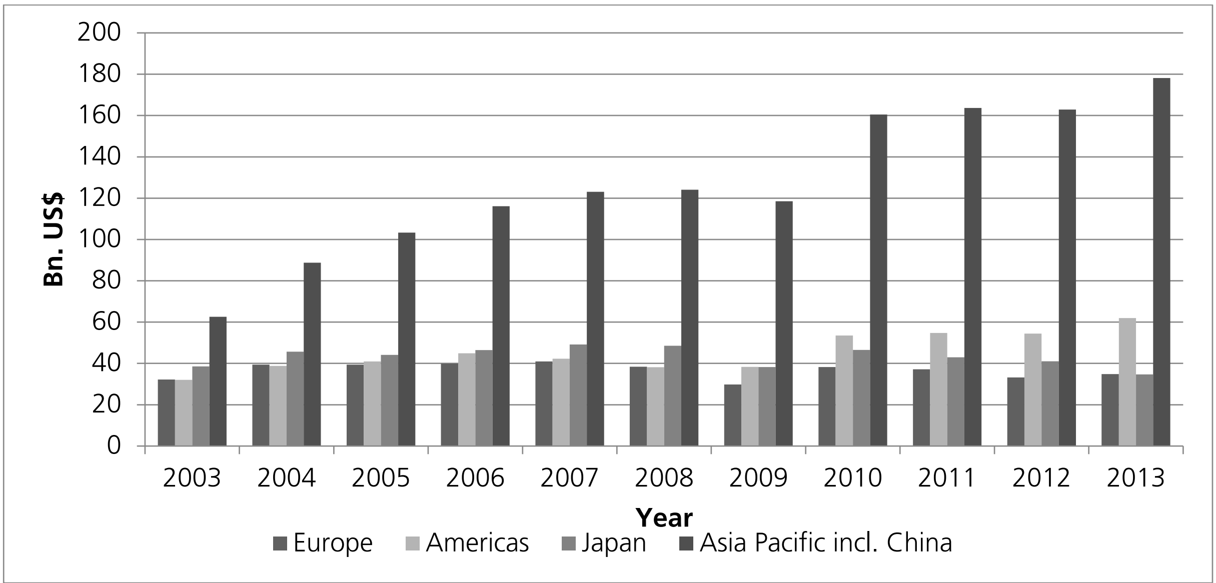
IC Insights 2014b

Figure 5: Comparing 300mm Wafer Capacity; Based on Foundry and HQ Location (4.2M Wafers, Dec-2014)



IC Insights 2014c

Figure 6: World semiconductor sales by region



Source: World Semiconductor Trade Statistics 2014 (Online: http://www.eeca.eu/esia/home; 15.03.2015)

Within this context, Figure 6 becomes interesting. It shows the amount of semiconductor products sold in the world regions. The main finding here is that the region with the by far largest amount of products sold is Asia Pacific. Additionally, the amount of sales in the region almost tripled between 2003 (from ca. $60 billion) and 2013 (to ca. $180 billion). Recently, the Americas (ca. $60 billion), Japan ($35 billion) and Europe ($35 billion) show a much lower demand for semiconductors. The message is: Asia is not only the main producer, it obviously also is the main consumer of semiconductor products.

3.3 Consequences for European regions and local firms

What follows from these observations is that the European position in global production of semiconductor-related products is comparatively weak. The industry's maturing process and evolution resulted in a fragmented value chain of which most parts moved to East Asia. This is true for the production of microelectronic products, but also for the generation of technologically relevant knowledge as well as the markets for microelectronic products. Furthermore, there are no signs that this is going to change. While new business and manufacturing models emerged, specializing on specific parts of the value chain, many companies (especially in Europe) focused on a business model without their own fabrication capacities (referred to as "fabless companies")[9] (Danish Technological Institute 2012).

The figures presented here give reason for another concern. As shown above, the industry is highly R&D intensive and especially large US firms invest many resources in R&D. R&D, however, is mainly conducted either in the headquarter locations or where the markets are. Yet the markets for semiconductor products shifted to Asia. This causes concern that even R&D activities will follow, at least in the mid- to long-term. Without investments in new manufacturing plants, sooner or later, closing production sites will result in a loss of human resources, know-how and equipment, which is difficult to regain. Europe would lose further ground in microelectronics.

Table 4: Top 10 Suppliers' Semiconductor Capital Spending in 2012 and 2013

Rank	Company	2012 ($M)	2012 (%)	2013 ($M)	2013 (%)
1	Samsung	12,225	21%	11,560	20%
2	Intel	11,000	19%	10,611	18%
3	TSMC	8,341	14%	9.709	17%
4	GlobalFoundries	3,800	6%	4,500	8%
5	SK Hynix	3,363	6%	3,146	5%
6	Micron	2,184	4%	1,935	3%
7	Toshiba	1,137	2%	1,630	3%
8	UMC	1,770	3%	1,098	2%
9	SanDisk	979	2%	859	1%
10	SMIC	499	1%	651	1%
	Top 10 Total	**45,298**	**77%**	**45,699**	**80%**
	Others	**13,742**	**23%**	**11,731**	**20%**
Total Cap Spending		**59,040**	**100%**	**57,430**	**100%**

IC Insights 2014d

Building next generation foundries will only be affordable by a handful of IDMs and foundries. Table 4 shows that only three companies (Samsung, Intel, TSMC), together accounting for 55 percent of all capital spent by semiconductor firms, invest sufficient capital to build a completely new foundry. Thus, only three global players might eventually be capable of running a new facility completely on their own. Whether or not they consider Europe as a potential production location depends on several aspects, which are discussed below. Taken together, catching up to large-scale, state-of-the-art production and first-class semiconductor manufacturing is likely to be an almost impossible task.

However, the described trends and specific economic rationales in semiconductor production are likely to constitute a large consolidation trend in the industry. While large-scale and mass production mainly remains in the hand of global players located in the US and East Asia, this could open a window of opportunity for European locations. Currently, remaining strength in

[9] Between these two poles sometimes different hybrid co-operation and service models emerged. These, however, basically differ in their commitment to own manufacturing capacities and the required capital investments are, due to increasing investment costs, coming along with new technological developments, likely to adapt a fabless model, too (Electronic Leaders Group 2014; Laursen et al. 2012).

microelectronics is concentrated in few European regions. The main microelectronic clusters here are Dresden in Saxony (Germany) and Rhône-Alpes (France). Additionally, the South- and East Netherlands, Flanders (Belgium) and Carinthia (Austria) are named as such. Each of these regions developed different specializations and comparative advantages in certain technological as well as sectoral niches. The European network initiative "Silicon Europe" recently conducted a regional SWOT analysis on its member regions and concludes that these five clusters together provide significant strength along the whole value chain. However, they also highlight the importance of cluster internationalization and actions to enhance the inter-European cluster cooperation as an enabler of specific (technological) topics (Silicon Europe 2014). In the following, some simplified and stylized facts on the three European world-class clusters are provided:

- Dresden in "Silicon Saxony" provides significant competences for high-volume chip production and hosts a fab for 300mm wafer production, which can be considered as current state-of-the-art, and is currently planning to double its production capacities. Furthermore, it hosts a number of equipment manufacturers and suppliers. Additionally, a number of high-class research institutions are located in Dresden. One weakness is the lack of a systems and final-products approach.
- The "DSP Valley cluster" around Leuven offers important technological research and development. The micro- and nanoelectronics lab Imec is an important player of world scale. Important potential is generated in microelectronics and embedded system design and development, but this is not fully exploited by the application-end of the value chain.
- Grenoble is renowned for the excellence of its research sector. Particularly, the CEA-Leti (1,500 people, around 250 patents per year, two to three start-ups created per year), 19 expert academic laboratories linked to microelectronics and local universities constitute a strong knowledge basis and contribute heavily to the patent production that put Grenoble at number five on the Forbes list of the world's most innovative regions. It hosts a number of global industrial players along the entire value chain, from materials (SOITEC) to the design and manufacturing of chips and systems (ST Microelectronics, E2V Semiconductors), as well as applications (Schneider Electric). One main weakness, however, is that a market-based approach is largely missing and the commercialization of technologies leaves room for improvement

All in all, the analysis concludes that common weaknesses for all regions are linked to the typical small and medium sized enterprises structure. This implies less impact on policy making, dependency on large enterprises and comparatively low production volume. Most of the clusters, however, see strong potential for future growth in the field of applications and application platforms. A clear expectation is that by combining competences from the different regions and exploiting cooperation potential between SMEs (the majority in all clusters) and Large Enterprises (the largest employment source), this field should become a strong European asset (Silicon Europe 2014).

The figures presented in this chapter seem to draw a rather pessimistic picture of the role that Europe and its regions are going to play in large-scale semiconductor production. However, though Europe (for now) has seemingly lost the still-ongoing race for "More Moore", current trends and dynamics in microelectronics, as well as in related industries, are going to create new technological paths and opportunities. These are likely to provide chances for future European industrial leadership, if perceived early on and supported with appropriate policies. These trends and opportunities are discussed in the next chapter.

4 New technological and economic developments

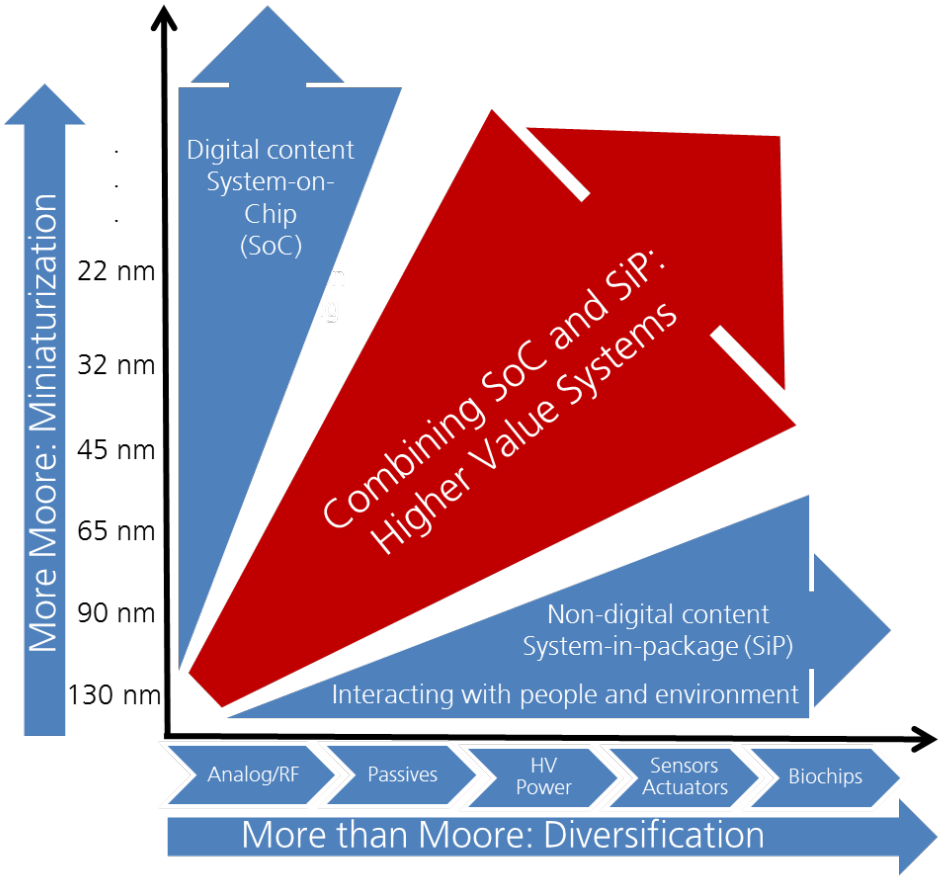
While the above-described components give the semiconductor-based hardware, and are directly related to digital content, a rather new trend denotes the increasing integration of non-digital functionalities. This leads to a new dimension, becoming increasingly important, the extension and connection with sensors and actuators, linking electronics to the outside environment.

4.1 Microelectronics and the modernization of production

A recent trend involves the integration of more and more functionalities enabling the interaction between micro-electronic hardware with the outside world. In doing so, the technology is evolving into non-digital contexts and applications. This evolution is driven and made possible by constant improvements on systems of integrated circuits or even complete "systems on a chip". These non-digital applications of micro-electronic components constitute a new promising avenue for new products and markets. This integration in non-digital functionalities is, therefore, referred to as "More than Moore". However, while providing value in multiple ways, they do not necessarily scale according to Moore's law. Thus, they are likely to underlie and undergo different dynamics than the "More Moore" paradigm. They should not been seen as a competing paradigm, but rather as a complementary and logical consequence of the emergence of new technological possibilities. These include e.g. the combination with analog and mixed-signal processing, passive components, high-voltage components, micro-mechanical devices, sensors and actuators as well as micro-fluidic devices enabling biological functionalities.

In sum, the integration of digital and non-digital functionalities into compact systems is likely to be a key driver for a wide variety of application fields, e.g. communication, automotive, environmental control, healthcare, security and entertainment (Arden et al. 2010). In general, "More Moore" represents and empowers the digital brain of an intelligent compact system, while "More-than-Moore" exploits its capabilities to interact with the outside world and the user (see Figure 7).

Figure 7: More Moore and more than Moore



Source: Own compilation following Arden et al. 2010

4.2 Beyond CMOS: Development of new technologies

As shown above, the microelectronics sector is more than the set of activities (or companies) that contribute to the design, production, packaging and commercialization of semiconductor devices. It shows all characteristics of a GPT and is better described as a "Key Enabling Technology". It has unique set of features which make it highly relevant for technological progress and economic growth in other sectors. Thus, examining its value chain has to take the "More than Moore"-technology-induced value creation into account. Figure 8 shows the global microelectronics industry value chain divided by its sub-systems along with the economic value as well as the share generated in Europe.

The global microelectronics value chain and the European position

The value chain entails an estimated overall sum of €2.536 billion. However, this is unequally distributed among its different parts. The figures demonstrate that semiconductor equipment, materials and components (Level 1 and Level 2) represent the minor share of the value created in the electronics industry (€445 billion / 18 percent of value creation). Modules and Boards (Level 3) make up for € 696 billion (27 percent of value creation). The largest share of value creation (€1.395 billion / 55percent of value creation) takes place in system solutions (Level 4). System solutions include "Stand-alone Systems" (€ 910 billion / 36 percent of value creation) and embedded systems, i.e. system solutions applied in other related sectors (accounting for

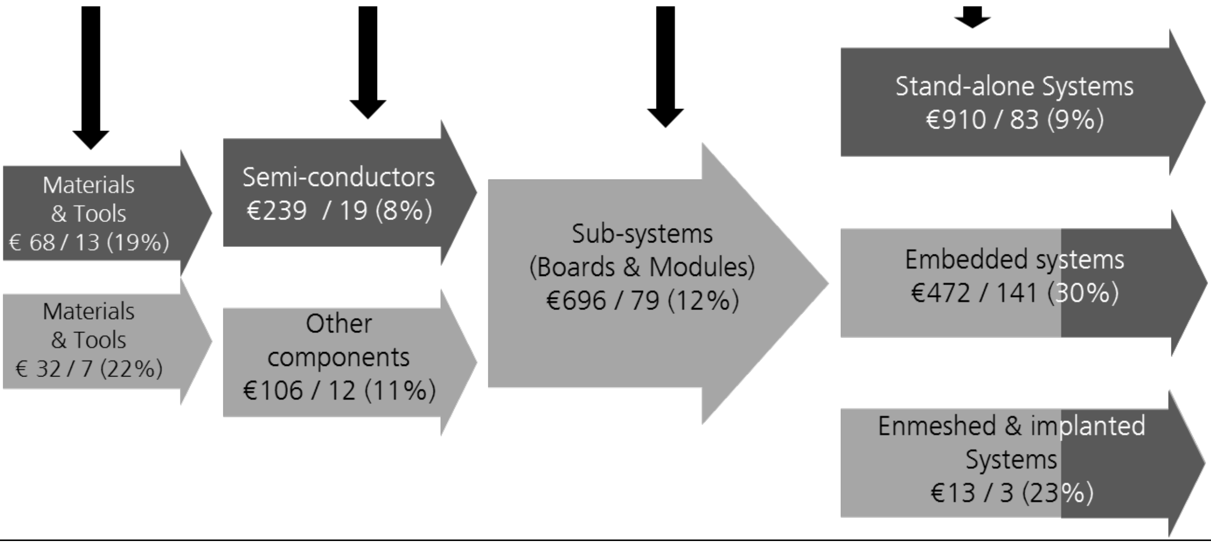
€472billion / 19 percent of value creation). Moreover, new and upcoming pervasion domains like agriculture, textiles or environmental technologies are included in system solutions and account for approximately €13 billion / 0.5percent of value creation.

In sum, less than half of the value generation in the electronics industry comes from the manufacturing of semiconductors, related components and its compilation in electronic sub-systems. The integration in complete systems, however, accounts for major parts of the value chain. Among those, purely digital stand-alone systems still maintain the larger share, but system solutions applied in other sectors already make up for about one fifth of the worldwide value chain.

At the same time Figure 8 shows that Europe accounts for, accumulated over all four levels, a total of €355 billion and a share of 14 percent of the global value creation. At level 1 (equipment and materials) Europe’s share is 20 percent, at level 2 (semiconductors and other components) it is nine percent and at level 3 (subsystems) it is twelve percent. Level 4 holds a relative strength of the European industry. It has a share of 16 percent and accounts for a total of €225 billion. According to the Electronic Leaders Group (2014), the embedded systems sector in particular constitutes a strong European sector. The countries of the European Union account for approximately 30 percent of the value created with embedded systems.

Figure 8: World microelectronics industry value chain, 2012 (in bn €)

Level 1: Equipment & Materials			**Level 2: components**			**Level 3: Boards & Modules**			**Level 4: Systems**		
world	EU	%	world	EU	%	world	EU	%	world	EU	%
€ 100	€ 20	20	€ 345	€ 31	9	€ 696	€ 79	12	€ 1395	€ 227	16



Source: DECISION Etudes & Conseil 2014; own compliation

Sectors with comparative advantage and growth perspectives

The numbers in Figure 9 give a rough indication on the existing potential and the competitive advantage that Europe maintains in sectors related to electronic production, i.e. application sectors for microelectronic products. Particularly those sectors where Europe is relatively strong and specialized, namely Automotive, Aerospace, Defense & Security as well as Industrial & medical, are expected to grow at the fastest pace.

Figure 9: Electronic production and annual growth Europe vs. World

Sector	World (2012)	Europe (2012)	CAGR 2012 - 2017
Automotive	9%	16%	7.0%
Audio/Video	11%	5%	-2.0%
Home Appliances	7%	6%	3.5%
Data Processing	24%	8%	1.1%
Telecommunication	24%	14%	2.8%
Aerospace, Defense & Security	8%	16%	4.3%
Industrial & medical	17%	35%	6.5%
Total	1.412 Bn$	197 Bn$	3.2%

Source: DECISION Etudes & Conseil 2014; own compliation

Europe obviously has a particularly strong position in industrial sectors with strong interdependencies to microelectronics and with significant growth potential. Electronic sectors which drive the European production are displayed in Figure 10, according to numbers provided by DECISION & Etude Conseil (2014).

Figure 10: Electronic sectors driving European production

Sector	Share in 2012	CAGR 2012 - 2017	Share in 2017
Total Europe	197Bn$	1.7%	215Bn$
Automation	19.8%	4.9%	23.1%
Automotive	16.4%	3.6%	18.0%
Power Electronics	4.7%	6.4%	5.8%
Aerospace	4.5%	6.9%	5.8%
Medical	4.8%	4.4%	5.4%
Security	2.9%	4.3%	3.3%
Transportation	1.4%	3.2%	1.5%
Smart Cards	1.1%	6.7%	1.5%
⇨ Agregated	55.6%	4.8%	64.3%

Source: DECISION Etudes & Conseil 2014; own compliation

4.3 Future technological and industrial opportunities and challenges

The considerations in this last chapter further illustrate the obviously weak position of the European industry in semiconductor and subsystem production. In complete stand-alone systems the situation is even worse. However, Europe's relative strengths are obviously within the embedded systems and materials sectors. The main reasons are strong industrial sectors (Automation, Automotive, Power electronics, Aerospace, Medicals, Security, Transportation and Smart Cards) that act as application sectors for the microelectronics technology. In basic products Europe's position in value creation is weakest (van der Velde et al. 2013). Nonetheless, the figures presented here, further confirmed by interviewees, give reason to believe that there is promising potential and a prospective growth for European microelectronics industry in more complex products as well as in "More than Moore" technologies. As shown above, this is unlikely to lie in the large-scale IC production. Due to public and industrial R&D capabilities, it is located in the area of materials and embedded systems. In conclusion, one is inclined to urge Europe to focus on these areas. In the long-term this might cause serious implications for industrial policy, which will be discussed in the following final section.

5 Implications for industrial and innovation policy: European perspectives

This essay has shown that the microelectronics industry has some unique characteristics which make it a special case for industrial policy to deal with. The following summarizing conclusions can be drawn:

1. Semi-conductor production is characterized by particularly high complexity and R&D intensity. The sector is unique in the sense that its technological development is very fast and its dynamics are unrivaled. Thus, R&D is an important ingredient for the industry and its production is the driver for new technologies and state-of-the-art products.
2. Establishing new state-of-the-art, large-scale production sites requires enormous capital investments, which are only affordable by a small number of corporations.
3. The fast dynamics observed in the past 50 years are currently, due to unsolved technological bottlenecks, slowing down.
4. The main share of production, generation of related technological knowledge and export of semiconductors takes place in East Asia and partly in the US. Only a minor share is allocated to Europe. Semiconductor industry develops geographically close to its demand and this causes concern that the disparities between Europe and the rest of the world will increase.
5. The domestic semiconductor industries in the dominant economies are perceived as industries of major strategic importance. Accordingly, they receive strong financial support (i.e. subsidies) from national governments in order to exploit their potential for future macroeconomic growth. Due to strong state interventions, the worldwide market for semi-conductors is far from being a free or fair trade market and Europe obviously faces disadvantages compared to other world regions, due to self-imposed restrictions and competition regulations.
6. Most countries seek to establish complete domestic supply chains since they want to reduce the risk of supply shortages. However, the largest share of value creation rests in the system application of semiconductor-related products.
7. Basic and purely IC-related semiconductor products like boards, modules and stand-alone systems are an application area where Europe’s position is weak. Its main strength rests in those sectors where digital and non-digital content are integrated and applied in “system in package” solutions, i.e. embedded and enmeshed systems.
8. The non-digital application and interaction of digital devices with people and environment constitutes the basis for sectors with high future growth perspectives and is likely to build the foundations for future growth trajectories in Europe.

All in all, a major obstacle is that without at least one location for state-of-the art semiconductor production, Europe completely depends on other locations for supply of high-performing digital content. Even more challenging is that without significant semiconductor production facilities, related R&D activities might relocate as well. Large firms might move their R&D departments and, subsequently, suppliers would follow (see e.g. Danish Technological Institute 2012 for further discussion). The loss of major parts of technology and production expertise, followed by degradation in leading edge R&D, is a dangerous threat to the European microelectronics industry and other related sectors. Besides further losses in production and employment, this would deepen existing fractures and cause further missing links in the micro-electronics related value chain. Additionally, a brain drain, a loss of highly skilled workers and industry specific knowledge, would significantly endanger Europe's prospective position in micro-electronics related industries. This could cause a severe obstacle to the European re-industrialization strategy, since it depends on the GPT micro-electronics as one of its main technological pillars for enhancing the competitiveness of its economy.

Even though it can be considered as a key technology where Europe has a weak position, a number of strengths in research, development and particularly in related industrial application sectors have the potential to constitute the main lines for prospective strategic and politically supported development of the micro-electronics industry in Europe. According to the interviews conducted with experts in the field, Europe still holds a strong position in R&D capabilities especially in basic as well as publicly funded applied research. Furthermore, it has a strong industrial base. Both aspects are reflected in a number of successful clusters with different strength and specializations.

In doing so, Europe has a particularly strong position in some sectors with strong interdependencies to microelectronics like automotive, aerospace, security, industrial and medicals. It is particularly the ability to transfer semi-conductor based elements into embedded systems that constitutes a European strength and is most likely to build the basis for future inter-sectoral innovation and growth. A further comparative strength is the existence of some market leaders and leading R&D in equipment, materials and some basic products (e.g. lithography, sensors, MEMs, Smart cards). Additionally, Europe has, due to a strong academic education and research system consisting of universities, public research organizations, in basic as well as applied research, a high number of highly skilled employees and professionals in the area of semiconductors and micro-electronics.

While we observe a number of threats, a set of capabilities and strength exists in the European micro-electronics sector. According to our interviewees and a literature review (c.f. Danish Technological Institute 2012), what seems to be missing is the recognition of the strategic importance of semiconductors for future technological trends, not only in the "More Moore" areas, but also the "More than Moore"-related sectors. This seems to be expressed additionally in an insufficient alignment of the European member states on a common semiconductor strategy. One of the main problems still is a lack of ability to convert the strong existing capabilities in R&D and even applied technologies into marketable products. Thus, the manufacturing industry is missing a strong high-tech focus. This also seems to be represented in the low share of proprietary IP, compared to East Asia as well as the US.

Taken together, the chances for Europe to address these issues and to create a strong micro-electronics industry lie in the formation of new markets and in addressing new technological and societal challenges. From an industrial policy perspective, however, the ability to set incentives is limited by European state aid regulation. Nevertheless, Europe should aim to create and steer lead markets by setting standards, exploiting existing leadership positions and, in particular, by leveraging the enormous potential residing in prospective "More than Moore" related value chains. The aim should be to increase demand not only the supply of semiconductor products. Thus application sectors for microelectronics should be supported by a strategy that supports "smart specialization". As proposed by the concept of smart specialization (c.f. section 2), policy instruments should therefore target areas with large potential for inter-sectoral innovation in combination with microelectronics as a GPT. In doing so, innovation policy should additionally take local specializations into account. In doing so, policy measures should be based on profound analyses of regional as well as sectoral specializations and comparative strength, because it is most likely that local networks and innovative regions are going to constitute the nuclei for new technological paths and models of value creation.

In addition to that, European industrial policy should carefully observe the ongoing technological development in the area of "More Moore" technologies. As already highlighted, the technological basis for future developments is constituted by the pace of technological development in semiconductors. Failing to keep up and to maintain at least one location for state-of-the-art production might result in loosing related corporate R&D activities and could significantly endanger the transfer of microelectronics into other related industrial sectors.

As shown above, the technological development in "More Moore" is currently slowing down, while experts are sure that the required technological breakthroughs are going to take place and this is going to accelerate the development again. The unanswered question is when this is going to happen. This in turn could open a window of opportunity, in the sense that it gives European industry the chance to at least close the existing technological gap, while maintaining its head start in other sectors. One of the big future challenges here is related to the "Internet of Things"/"Industry 4.0". The technological and economic foundations for future value creation are going to be closely linked to the combination of both faster and more efficient semiconductors ("More Moore"), but also the intelligent construction and integration of embedded/cyber-physical systems ("More than Moore"). Thus, the second challenge, besides enabling inter-sectoral innovation, is to maintain high-performing, large-scale, well equipped and state-of-the-art research and production capacities. This, however, is going to require enormous investments in state-of-the-art semiconductor production and calls for public support to state-of-the-art foundry development in Europe.

All things considered, innovation policy should try to focus on existing strength and on the one hand try to pave the way for a strategic approach to promote the technological basis of the sector and on the other hand support cross-fertilization of other industries in order to exploit the full economic potential of the technology. Therefore, the following recommendations can be drawn:

Firstly, the EU and particularly the member states should recognize the strategic importance of an integrated and common strategy. To promote the microelectronics industry should become a priority on EU as well as national policy level - regardless of local interests.

Secondly, in the long-term, access to high-tech infrastructure should be ensured. The current slow-down in technological development might open a window of opportunity for Europe to catch up to other leading economies in "Moore more" technology. However, enabling future investments in state-of-the-art semiconductor production will require:

- a review of investment rules by the European government. They should carefully monitor and evaluate recent as well as ongoing trade and investment policies of the major competing countries presented in this report. In doing so, European policy makers should learn from the other countries strategies and develop instruments and framework conditions (i.e. legal and technological) that allow the efficient support of microelectronics industry. Obviously, it is time to follow examples of competing countries and help investments instead of hindering them.

- Joint efforts between public and private actors as well the European member states in order to raise the significant capital which will be required to host at least one foundry for 450nm production in Europe. The question will be, if the member states are willing and able to find a European solution, to define a suitable location for this foundry and to agree on a common strategy as well as way of co-financing it.
- Careful development, monitoring and ongoing forecast of technological roadmaps to support the development and implementation of mid- and long-term strategies in innovation and industrial policy will be needed. This should include not only semiconductors, but the whole value creation chain in the micro-electronics industry (including system solutions).
- It should not be forgotten that Europe needs to secure sources of hardware and critical raw materials needed for semi-conductor production. This includes the support of recycling. One approach to do this is to try to insist on free trade and open markets for semi-conductor products as well as raw materials.

Thirdly, however, the design and implementation of concrete support mechanisms and tools should be smart in the sense that it should focus on existing strength in industrial sectors, private and public research. This study has shown that there is a substantial chance for the European knowledge-based economy in the "More than Moore" technologies, i.e. inter-sectoral diversification and occupation of interfaces. The exploitable potential lies in number sectors clustered in several European locations. Furthermore, Europe still hosts some leading edge research facilities, few global players, a number of SMEs active in micro-electronics and some 200 and 300nm foundries. Considering that the large-scale production in Europe is currently disadvantaged, diversification via "More than Moore"-technology offers a way to deal with this handicap at least in the short- and mid-term. Leveraging existing leadership positions and potential, however, requires inter-sectoral as well as inter-regional innovation activities as proposed in the Smart specialization concept (see introduction). Thus, support activities should:

- aim at enhancing the dynamic capabilities of local firms and clusters by means of support of collaborative research activities. Particularly, the large number of microelectronic SMEs should be addressed and enabled to contribute to emerging value chains.
- Supporting entrepreneurial activities should help to exploit potential for new models of value creation.

- Support activities should be accompanied by further investments in public as well as private research activities, in order to ensure a leading edge position in embedded, respectively cyber-physical systems.
- Potential for public-private collaborations and strategic alliances in research activities should be leveraged in order to ensure the transfer of excellent research into high-tech products.
- Activities should concentrate on areas and regions of comparative advantage and strength. However, a European perspective is highly recommended in the sense that a European strategy should aim to cover complete value chains and employ complementary strength across regions.
- One of the main strengths of the European microelectronics sector is access to highly skilled workers, engineers and young academics in natural sciences. It will be crucial to maintain this source of competitive advantage in future.
- The setting of standards will play a major role for the creation and steering of lead markets. Thus, Europe should aim to strengthen its position in strategically important standardization processes.
- Furthermore, public procurement in areas of high strategic importance could constitute a means of triggering innovation activities and the establishment of new markets.

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