The Future of Semiconductor Intellectual Property Architectural Blocks in Europe

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1. Executive Summary

Semiconductor intellectual property (IP) blocks, also known as IP cores, are reusable design components that are used to build advanced integrated circuits (ICs). It is typically impossible to create new IC designs without pre-designed IP blocks as a starting point. These design components are called "intellectual property" blocks because they are traded as rights to use and copy the design. Firms that focus on this business model are often called "chipless" semiconductor firms.

IP cores are perhaps the most knowledge-intensive link in the information economy value chain. They define the capabilities of billions of electronic devices produced every year. As all products are becoming increasingly intelligent and embedded with information processing and communication capabilities, future developments in semiconductor IP will have a profound impact on the future developments in the overall knowledge economy and society.

At present, the IC industry is approaching the most fundamental technological disruption in its history. The rapid incremental innovation that has led to exponential growth in the number of transistors on a chip and expanded the applications of ICT to all areas of human life is about to end. This discontinuity—the end of semiconductor scaling—opens up new business opportunities and shifts the focus of ICT research to new areas.

The main objective of this study was to describe the current state and potential future developments in semiconductor IP, and to relate the outcomes of the study to policy-related discussions relevant to EU and its Member States.

Key results of the study include the following:

There are over 150 European firms that license semiconductor IP. Globally, among the top 20 independent IP vendors, nine are headquartered in the EU or have substantial development activities in European countries. At present, many IP vendors have difficulties with profitability and growth.

The approaching technology disruption will, however, create new business models and potentially lead to rapid expansion of innovative activities in semiconductor-based industries.

Asian countries are implementing focused policies that aim at creating and supporting semiconductor ecosystems that span from design to final system production. China—the largest semiconductor consumer worldwide—is still catching up technology leaders both in design and chip fabrication. The slowing down of rapid advances in the IC fabrication technology will, however, make this lag increasingly unimportant. There are now about 500 semiconductor design enterprises in China, although only a handful are actively marketing their IP outside China. China may be relatively well positioned for the new business logics and IP architectures that emerge at the end of semiconductor scaling in the next years.

Product reconfigurability is becoming increasingly important also in semiconductor hardware. Reconfigurability means that processing architecture can be changed according to the needs of the computational problem at hand. This will change the traditional division of labor between software and hardware, and make high-performance computation possible with relatively low-performance processing technologies.

When reconfigurable application specific hardware architectures are combined with low cost implementation technologies, radically new domains of innovation become possible in the ICT industry. New downstream innovation models will become important. The realization of emerging opportunities will, however, critically depend on wide access to design tools and competences. To an important extent, the future of semiconductor IP depends on competence development that occurs in open innovation ecosystems and outside formal educational settings.

Several entry barriers limit growth in this area. Research policies that encourage the development of open design ecosystems, low-cost design-to-implementation paths, new forms of competence development, and new computational models could have high impact on the future of IP architectures in Europe. As the IP industry and its knowledge processes are based on global networks, regional policies have to be formulated in a global context, for example, as policies that facilitate the formation of strategic ecosystem hot-spots. In Chapter 9, the report suggests several concrete initiatives that could support policymaking and accelerate growth in this domain.

2. Introduction

2.1. Study Theme and Motivation

This study describes the current state and future development scenarios for pre-designed semiconductor intellectual property cores (IP cores). IP cores, also known as IP blocks and “virtual components,” are designs that can be used to build integrated semiconductor devices (ICs) and “systems-on-chip.” They are widely marketed by European, American and Asian firms, and they are critically important building blocks in current and future digital products. Firms can re-use internally developed IP cores in their own products or they can gain revenues through licensing, royalties, and customization of these pre-designed components. There are over 150 European firms that sell licenses to their IP cores. At present, the globally leading vendor is the ARM Holdings plc, whose IP cores were used in about every fourth programmable electronic device manufactured in 2007.

As technology allows now billions of transistors on one semiconductor die, it is impossible to build new chips from scratch. Instead, designers start with large libraries of semiconductor IP and construct new chips by combining, modifying, and complementing earlier designs. Often dozens or more IP blocks are combined in one chip to create application specific integrated circuits (ASICs), application specific standard products (ASSPs), and complete systems-on-chip (SoCs). These, in turn, provide the foundation for products such as mobile phones, television desktop boxes, digital cameras, MP3 players, automobile engine and industrial process controllers, toys, smart cards, hearing aids, heart monitors, and basically everything that uses or processes information and data.

As the design of IP cores often requires expertise both in microelectronics design and demanding application domains, specialized firms that develop IP cores represent a highly knowledge-intensive segment of the ICT industry. IP cores are used in almost all new semiconductor chip designs, and they are critically important for successful introduction of new electronics products. The future of this industry segment is therefore of major importance to the European information economy.

In the history of semiconductor industry, manufacturing, assembly and testing activities have relatively rapidly moved to countries with low manufacturing costs. Today, with the exception of

Intel, IBM, Samsung and few other integrated device manufacturers (IDMs), the actual fabrication of semiconductor chips is dominated by firms located in Taiwan, China, and Singapore.[1] Also Intel and IBM are increasingly producing leading-edge semiconductors in Asia. Intel started the construction of its first semiconductor manufacturing plant in China at the end of 2007, investing $2.5 billion in the project. In December 2007, IBM, in turn, licensed its advanced 45 nanometer technology to SMIC, now globally the third-largest independent semiconductor manufacturer, based in China. The present study, therefore, also discusses the current and potential geographic relocation of design activities of semiconductor IP cores, and its possible policy implications.

The semiconductor industry is today in a historically unique situation. For almost five decades the industry has been driven by continuous miniaturization. The size of transistors on semiconductor die is now measured in nanometers. The smallest features on leading-edge chips are now down to three atomic layers. As the cost of manufacturing has remained almost constant per square millimeter, transistors are now tens of millions times less expensive than they were just three decades ago.

This improvement is a key factor in the emergence of the information economy and knowledge society. The predictability and constancy of improvements in the semiconductor industry has organized business logics in the industry and also widely beyond it. Many industries now explicitly or implicitly rely on continuous technical progress in the semiconductor industry. In the near future, this fundamental driving force will evaporate. Miniaturization is becoming increasingly expensive, its technical and economic benefits are declining, and new alternative sources of value are emerging in the knowledge economy.

This technical discontinuity will have huge implications. It will show up in macroeconomic indicators of productivity and growth, and it will make us ask why, exactly, smaller transistors were considered to be better. At the same time, new business models will emerge, and new sources of value will be defined and appropriated. Value added in design is becoming increasingly important as incremental technical improvement slows down. The present study claims that to understand the emerging opportunities, we need to understand the "chipless" model, which focuses on creating re-usable intellectual property blocks and processing architectures.

1 In 2007, the Taiwanese TSMC and UMC, the Chinese SMIC, and the Singaporean Chartered Semiconductor were the leading independent semiconductor foundries, with market share of 71 per cent.

Semiconductor IP represents a very knowledge-intensive part of the ICT industry, and one of its highest value-adding activities. Basically, it packages and resells pure knowledge. Changes in the semiconductor IP sector, therefore, are potentially important for the USD 1.5 trillion electronics industry, as well as for the rest of the knowledge economy.

2.1.1. European Intellectual Property Architectures in the Global Context

Europe is today a relatively strong player in the semiconductor IP field. Although European and global semiconductor firms now manufacture many of their products in Asia, Europe has several leading IP firms and over 150 small IP vendor firms. The semiconductor wafer fabrication is now dominated by dedicated Taiwanese, Chinese and Singaporean firms, and also large IDMs now increasingly outsource wafer fabrication to Asia. The leading edge general-purpose microprocessor production, in turn, is led by traditional integrated device manufacturers such as Intel, AMD, and IBM. Although semiconductor design is increasingly done in countries such as India, Europe still has strong capabilities in IP creation, and good possibilities to stay in the leading edge in the semiconductor IP industry. European researchers have also developed new innovative processing architectures, and several semiconductor IP startups have been launched in the EU as a result of university research.

In geographical terms, the U.K. is the leading EU country in semiconductor IP, though successful IP firms exist in most EU countries. We describe the European IP vendors in more detail in subsequent chapters of this report. We also highlight some of the factors that have led to geographic concentration of semiconductor design activities on the global and European levels.

Although this study estimates that the revenues generated by the chipless semiconductor firms are less than one percent of the total semiconductor industry, it is important to understand the reality behind the numbers.

First, the semiconductor IP industry creates inputs for the semiconductor industry. It is therefore not possible to estimate the economic impact of semiconductor IP simply by comparing these two industries using their revenues. In fact, the size of the IP market should be compared with the semiconductor design services market. The semiconductor IP industry is essentially about semiconductor designs that are sold as pre-packaged products. Often the package comes with consulting and customization. At one extreme, the design work is done to the specifications of a customer. In that case, market analysts categorize the activity as design service. When the design is sold as a license to use and copy a design component, the activity is categorized as IP.

Gartner Inc. estimates that the global semiconductor design services revenue in 2008 was about USD 1.7 billion. This is almost exactly the size of the chipless semiconductor market. In other words, about half of the semiconductor design market consists of design services and about half pre-designed IP blocks. As IC design houses also extensively reuse their internally developed IP blocks, the exact proportions of revenues are, however, quite impossible to estimate accurately.

Second, the majority of commercially used semiconductor IP is not visible. For example, Semico estimates that about four or five times more reusable IP blocks are developed internally than are sold on the market. The volume of reusable IP design activities, therefore, may well be five times bigger than market studies estimate. As the processes for managing and packaging IP blocks mature inside semiconductor firms and as it becomes increasingly necessary to create reusable IP as the complexity of designs increase, this internally developed IP can relatively easily be used to create additional revenues. Potentially, the visible IP market could rapidly increase as such internal IP would enter the market.

In general, IP creation is among the highest value adding activities in the ICT production, and its economic impact is often grossly underestimated. The semiconductor IP segment, therefore, represents interesting policy and business opportunities, as the ICT industry enters a period of technical disruption in the next years.

2.2. Scope of the Study

In the present study we define intellectual property cores as a pre-designed components that can be combined with other design elements to form a functional system. Traditionally, IP cores have been implemented on semiconductor die, either in application specific integrated circuits (ASICs), or on field-programmable gate arrays (FPGAs).[2] Emerging technologies, such as printed organic electronics, however, can potentially also be used to implement IP cores in the future. Although the

2 The appendix describes ASIC and FPGA design processes in more detail.

focus of the study is on semiconductor IP cores, it takes into account also developments occurring beyond the present semiconductor industry.

New technologies, including carbon nanotubes, graphene transistors, self-organizing molecular devices, and quantum computing can potentially bypass the physical limits of known semiconductor technologies. Eventually, such radical new technologies could substitute current technologies and enable progress in ICTs. The present study does not discuss these future technologies in any detail, for a very simple but important reason: It starts from the observation that even if radical new technologies would be available today in industrial volumes, their deployment would require knowledge, manufacturing technologies, and design methods and tools that are radically different from those currently used in the semiconductor industry. The underlying claim is a rather strong one. Even if, for example, new carbon-based transistors and full-scale manufacturing methods for them would exist today, the industry will face a major technical disruption that will rewrite the rules under which it has operated for the last several decades. This disruption will occur independent of whether the new technologies are there today, or whether they will be there in thirty years time. Although the full story obviously is more complicated, the present study empirically focuses on the current industrial reality and simultaneously argues that the continuous progress that characterized the development of ICTs is about to end. The analysis of future developments in the semiconductor IP is therefore based on charting the current business landscape and generic patterns of technology development, instead of focusing on possible scientific breakthroughs and innovative new technologies. A further justification for this approach is that there are no known alternatives for the currently used technologies that could be manufactured in industrial volumes in the foreseeable future.

The specific empirical focus of the present study is in IP cores that can be programmed and combined into larger processing architectures. The study defines such IP cores as *IP computing cores*. These are, typically, programmable microprocessors, micro-controllers, digital signal processors, analog-digital mixed-signal processing blocks, and configurable computing architectures. As computing cores typically require additional IP components to create a fully functional chip or a system-on-chip, these complementary components are also taken into account when relevant.

For the purposes of the present study, it is not necessary to categorize different types of semiconductor IP in any great systematical detail, although it is useful to understand that different economic constraints and innovation dynamics underlie different IP product segments. In practice, market analysts often distinguish many different types of IP to segment the market and to cluster vendors. Such segmentation is not trivial, and methodological differences lead sometimes to widely varying estimates of IP markets. In practice, IP is packaged in many ways, vendors continuously develop their business models, and entries, exits and mergers change the business landscape fast enough to make data barely comparable across years.

Market studies sometimes differentiate between two types of semiconductor intellectual property: design IP and technology licensing. Technology licensing is used to transfer rights to use patented inventions. Design IP, in turn, consist of documented designs that the licensor can use as components in the licensor's own designs. According to preliminary data from Gartner Inc., the global semiconductor design IP market was USD 1.486 billion in 2008, whereas semiconductor IP technology licensing was 586 million.[3] The various semiconductor IP categories used by Gartner are shown in Table 1.

		USD millions	Growth %
Processors	Microprocessors	582	6.2
	Digital Signal Processors	52	21
Physical IP	Analog and Mixed Signal	205	22.4
	PHY	149	8.4
	Memory cells/blocks	132	4
	Physical library	62	-6
Other IP	Fixed function signal processing	182	16
	Interface controllers	79	5.5
	Block libraries	29	-16.5
	Infrastructure IP	34	3.1
	Miscellaneous IP	28	-11.4
	Controllers and peripherals	6	-15.2
	Total design IP	*1486*	*8*
	Technology licensing	587	6.8
	Total IP	**2073**	**7.7**

Table 1: Semiconductor IP in 2008, as categorized by Gartner Inc.

3 The data is a preliminary estimate for 2008. One should also note that the numbers do not add up. The total volume of the various IP segments in the table is USD 1,540 million. Assuming that technology licensing is counted as a separate IP category, the total market would be 2,127 million.

In the present study, we use a wide variety of market studies, industry reports, business news, and primary data collected on IP firms and their activities. We have also conducted several case studies that focused on the histories and growth patterns of selected IP firms. Going beyond a simple description of the current state of the IP segment, we also interpret the current situation and future developments in the broader contexts of globalization and technology and innovation studies.

In the next chapter, we discuss major socio-economic trends, as economies, products, and organizations enter the new knowledge-based era. We focus on the challenges of traditional intellectual property, new innovation models, and policy. Semiconductor "intellectual property" is often a misleading term, as it tends to put the semiconductor design segment into a context where the concept of intellectual property and intellectual property rights would be central. This is rarely the case in practice, as can be seen during the following chapters. Yet, the semiconductor IP segment is characterized by the fact that it trades intangible assets, and the structures of intellectual rights regimes are important for its future. We highlight some key issues, and provide some references for further discussions. Similarly, we briefly revisit some key themes of recent innovation research, as they inform and underlie various sections of the report, including its policy proposals. The chapter also discusses the possibility that the wide use of ICTs has actually changed the fundamental conditions for making policy. We frame this discussion in the context of long waves of economic growth and the impact of key technologies, showing how developments in the semiconductor technology potentially destroy the historical patterns of growth and crisis, also known as the Kondratieff waves. The aim of the chapter is to give some perspective to the rest of the study and to help the reader think about changes that occur outside the semiconductor industry that could shape its future in important ways.

The following chapter will then switch from this conceptual discussion to a more data-oriented approach. It describes the current reality of the semiconductor industry, describing its business models and value creation activities both in qualitative and quantitative terms.

We then focus on the semiconductor IP industry itself, providing data on the IP market and supply, including geographic patterns of production. To get a better understanding of what typical IP firms actually do, we provide a detailed description of Swedish IP firms and a brief outline of the historical development of the largest IP vendor, ARM Ltd.

The next chapter will then move back from details to the big picture. We describe the main historical drivers in the semiconductor industry, first focusing on the continuous miniaturization and its impacts, and then discussing economic trends and patterns of internationalization. In discussing the historical development of internationalization, we highlight the factors that underlie the prominence of Silicon Valley and East Asia as global hubs in semiconductor production.

Based on innovation and technology studies, we then try in the following chapter to uncover major drivers that could shape the future of semiconductor IP and information processing architectures. The chapter is obviously speculative in nature, as we talk about generic trends that cannot be verified at this point of time. Specifically, we discuss the future of Makimoto Waves that have been claimed to drive the industry through cycles of standardization and customization. We also propose a new model that links reconfigurable IP architectures to user-centric innovation models.

One question of intrinsic interest to regional policymakers is the future potential of China as a semiconductor IP creator. In the history of semiconductors, production tasks and segments of value chains have rapidly moved to East Asia, and, more recently, to China. We describe the status of the IC design segment in China, highlight some recent policy issues, and evaluate five possible trajectories that could make China a prominent IP actor.

Finally, the report suggests some policy implications. We present a generic model of entry and exit in the IP segment, and use it to highlight key areas where policy could make a difference. These include new approaches for competence development, expanded access to design tools in open development ecosystems, and new low-cost realization paths for designs and experimentation. We further highlight the need for new computational models, including reconfigurable hardware processing architectures, and suggest that latent opportunities could be made visible and explicit by a new type of roadmap activity organized around small IP vendors and developers. We also point out some potentially important areas for policy-related research. These include new approaches for regional policies that facilitate the growth of local hot-spots in global innovation ecosystems, and research on the enablers of the open source development model in the hardware domain. The latter we consider important, as the open source model has shown its potential to lead to very fast growth in the software domain, as well as its capability to reorganize existing industries and business logics.