Industrial Research and Innovation Monitoring and Analysis (IRIMA II)

D3.2. Second Report on Global Value Chains

R&D and innovation activities in companies across Global Value Chains

Summary report

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1. Introduction

1.1. Background of the study

The world economy has changed in significant ways during the past several decades, especially in the areas of international innovation activities and industrial organization. Two of the most important new features of the contemporary economy are the globalization of innovation, production and trade, which have fuelled the growth of industrial capabilities in a wide range of developing countries, and the vertical disintegration of transnational corporations, which are redefining their core competencies to focus on innovation and product strategy, marketing, and the highest value-added segments of manufacturing and services; while reducing their direct ownership over 'non-core' functions such as generic services and volume production. Together, these two shifts have laid the groundwork for a variety of network forms of governance situated between arm's length markets, on the one hand, and large vertically integrated corporations, on the other[1].

In 2010, the Commission adopted the flagship initiative "An Integrated Industrial Policy for the Globalisation Era" (COM(2010)614) in the context of the Europe 2020 strategy for smart, sustainable and inclusive growth. This initiative sets out a fresh approach to industrial policy, emphasising the importance of industry for the EU economy. It focuses on strengthening industrial competitiveness to underpin growth and jobs and to enable the transition to a low-carbon and a resource-efficient economy. The Council and the European Parliament strongly endorsed this approach, requesting its implementation and further development. In October 2012 the Commission adopted an Update of the Industrial Policy flagship initiative, the Communication "A Stronger European Industry for Growth and Economic Recovery" (COM (2012) 582 final). After an extensive public consultation, the Commission proposed to jointly focus investment and innovation on six priority action lines: advanced manufacturing technologies (for Clean Production), Key Enabling Technologies (micro- and nanoelectronics, advanced materials, industrial biotechnology, photonics, nanotechnology and advanced manufacturing systems), bio-based products, sustainable industrial and construction policy and raw materials, clean vehicles, and smart grids. The Communication includes policy proposals to enhance performance in global markets. It proposes that EU companies would be supported and accompanied in their internationalisation process, in order to increase the share of internationally active EU SMEs (currently estimated at 13%).

The current industrial policy, as set out in the Industrial Policy Communications of 2010 and 2012, remains in place but it has been prolonged and reactivated by a recent Communication in January 2014 (EC, 2014, , For a European Industrial Renaissance). The new Communication stresses the importance of full and effective implementation of industrial policy in the EU and focuses therefore on concrete measures, such as pursuing industrial modernisation through investment in innovation, resource efficiency, new technologies, skills and access to finance. Investment on the innovation process is pivotal for industrial recovery, thus understanding the role of R&D and innovation in a firm's delocalisation and geographical dispersion of the value chain at EU level, is of high importance. This is all the more important because firms are increasingly relying on internationally dispersed sources of knowledge (especially multinational enterprises that

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1 Gereffi, Gary; Humphrey, John; Sturgeon, Timothy (2005). The governance of global value chains. Review of International Political Economy,Vol. 12, Iss. 1

account for most of private R&D expenditure), and because the non-traditional locations (i.e. emerging economies) are climbing up the hierarchy of MNE's R&D and innovation activities, disrupting the well-known patterns of re-localisation and the overall architecture of global value chains.

In a more recent communication (2017), The European Commission also emphasizes that we have arrived in "a new industrial age" with economic, societal and environmental transformations and technological breakthroughs that occur at fast pace (e.g. robotics, Internet of Things, artificial intelligence). Within this new industrial age, the integration of industry in global value chains is becoming more key. Therefore, it is argued that the EU requires important efforts to maintain and reinforce its' industrial leadership. New initiatives have also been unveiled for a smart, innovative and sustainable industry. One important goal hereby is to further facilitate the integration of European companies in global value chains in R&D and innovation which are considered as the essential drivers of industrial competitiveness. In this Communication it is also stressed that there has to be a focus on "strategic value chains" in new technology which has to be well coordinated and financed by public authorities and industries from several Member States. The present study has the aim to further advance our knowledge on the geographical and functional fragmentation of R&D and innovation activities from a company perspective. For this purpose, it has built upon the state of the art knowledge on firms' global research and innovation networks and Global Value Chains (GVCs). The concept of GVC refers to the increasing geographical fragmentation (at worldwide scale) of the full range of activities that firms engage in to bring a product to the market, from conception to final use (i.e. including design, production, marketing, logistics, distribution and support to customers). This study also aims to further complement the analyses conducted at the European Commission (e.g. recently DG RTD conducted an analysis on the drivers, geographical dispersion and impact of international R&D activities, but in this study they did not take the large heterogeneity of sub-functions of R&D activities into account that may have an impact on all these aspects). As this study also aims to further unravel the strategic competences of the EU's industry in global value chains, it can also serve as relevant background info for the recently proposed European framework for the screening of foreign direct investments into the European Union (COM(2017)487)[2].

1.2. Objectives of the study

The objective of the study is to better understand the geographical and organizational patterns of corporate R&D and innovation across GVCs and their interactions with home and host-countries' economies and policy initiatives. In addition, a better understanding of the drivers and barriers to improving the location of high-value creation and knowledge-intensive activities in Europe and the competitive position of EU industry in strategic GVCs is aimed for.

The study focused on the following questions for companies in selected sectors which are strategic for European competitiveness:

(a) How do companies organise their R&D and innovation (R&D&I) activities across GVCs?

(b) What is the relationship between R&D&I locational decisions and the location of production activities?

[2] Within this framework, the European Commission – together with the Members States – wants to "screen third country foreign direct investments in the EU in strategic industries, infrastructure and key future technologies, or other assets that are important in the interests of security and protection of access to them" in order to enable Europe to preserve its essential interests.

(c) Which industrial differences can be observed?

(d) How functions/activities are sliced (or not) across different subsidiaries, external partners and different territories?

(e) Which corporate governance mechanisms and modes sustain corporate R&D and innovation across GVCs? (alliances, subcontracting, collaborative contracts, IP licensing, subsidiaries chain, …)

(f) What are the main implications for the locational strategy of EU firms, and for EU innovation/ attractiveness policy? Which corporate challenges can be derived?

(g) Which policy challenges can be derived?

Furthermore, the study has focused on the analysis of individual companies in selected sectors which allow generating an overall representative picture from the firm perspective. The study has been based on empirical evidence and has aimed to better explain the link between R&D and innovation, and the geographical dispersion thereof in Global Value Chains (GVCs). The study has also provided a synthetic analysis of firms' perceptions and opinions about future drivers, determinants and barriers for research and innovation investments in Europe, in relation to location decisions and overall competitiveness issues.

1.3. Structure

This study provides a summary of all activities, findings and conclusions of the entire project. The report includes:

- Chapter 2: details the study approach and the methodology used in the project;
- Chapter 3: provides an overview of the functional and geographical fragmentation of R&D&I within the pharmaceutical sector, the automotive sector, the aerospace sector and the ICT sector;
- Chapter 4: provides a summary of the locational determinants of international R&D&I activities, its governance modes, the impact of these activities on the home and host region and the interactions with local ecosystems;
- Chapter 5: provides an overview of the attractiveness of Europe for R&D&I activities within the selected sectors (pharmaceuticals, automotive, aerospace, ICT);
- Chapter 6: provides a summary of the policy toolbox that we have developed as part of this study;
- Chapter 7: provides a brief conclusion of the project;
- An annex with complementing information;
- A list of all references used throughout the project.

2. Study approach and methodology

2.1. Approach

The main objective of the study is to analyse the geographical and organizational patterns of corporate R&D and innovation across GVCs and their interactions with home and host-countries' economies and policy initiatives to create a better understanding.

Figure 1 sketches the overall approach of this project with the different tasks, activities and deliverables.

Figure 1: Overview of tasks and activities

Tasks	Activities	Deliverables
Task 0: Kick off Month 1	- Common understanding of objectives and approach	**kick off meeting** (July 2016)
Task 1: State of the art and present challenges Months 1-2	- identification of relevant publications - collection and screening - review and synthesis - desk research and data analysis	**Deliverable 1**: synthesis literature review & fine-tuned analytical framework
Task 2: Characterization of corporate RDI GVCs Months 2-14	- Fine-tuning methodological approach - selection of companies - 10 case studies and monographs - 60 interviews - cross-cases analysis	**Deliverable 2**: fine-tuned approach & proposal for selection of companies **Deliverable 3**: description of company-level GVCs **Intermediate workshop** (8th IRIMA Workshop, March 2017)
Task 3: Assessing the territorial drivers and impact of RDI GVCs Months 7-14	- Selection of "relevant GVCs RDI locations" - Assessment of place-based drivers & impacts - analysis of regional characteristics & strategies	**Deliverable 4**: Assessing the place-based impacts: drivers from company perspective **Deliverable 5**: Assessing the place-based impacts: regional capabilities for RDI GVCs location
Task 4: Policy toolbox for the upgrade of the EU industry in GVCs Months 14-16	-Identification of policy challenges for GVCs governance - design policy tool	**Deliverable 6**: Policy Toolbox on GVCs
Task 5: final report Months 16-19	- Draft final report - Final report	**Final Workshop** (December 2017) **Deliverable 7**: Summary report **Deliverable 8**: Final report and executive summary (January 2018)

2.2. Methodology

4 different methodologies have been used to examine the topic: a literature review, a data analysis, interviews and case studies

- The **literature review** focused on obtaining a comprehensive and recent overview of the existing evidence on the interrelation between R&D and innovation localisation decisions and their impact on the home and the host countries. All references that have been used throughout the project can be found at the back of this document. References to company reports or websites of the firms that have examined in the case studies have been removed in order to safeguard the confidentiality.
- **Data analysis** has been performed (mainly based on the 2016 EU R&D Scoreboard and patent data) to obtain an overview of R&D activities and innovation across global value chains in Europe by specific companies.
- Information from the desk research has been complemented with multiple **interviews** to obtain a more comprehensive assessment of corporate internationalization strategies, organizational processes and challenges. 10 companies have been selected for this purpose (see below). Interviews with company managers have also been complemented by interviews with external sector experts.
- **10 case studies** at company level have been conducted, distributed across three of the most knowledge-intensive sectors (with the highest overall R&D expenditures) of the European Union. These case studies enabled us to better understand the geographical and organizational patterns of corporate R&D and innovation (R&D&I) activities across global value chains and their interactions with home and host countries' economies and policy initiatives. Additionally, the case studies enabled us to gain a better understanding of the locational drivers and barriers to improving the attractiveness of Europe as a location for R&D&I activities. The case studies have also shed more light on the competitive position of the European Union in strategic GVCs. A 'case' refers here to the entire global value chain of a company's product (group). More specifically, this study has looked at R&D&I activities (both R&D and non-R&D) within the global value chain. This global value chain covers the sequence of operations going from early research activities to the marketing of the developed products. The value chain can also include external partner firms and (research) institutions when the company outsources activities or engages in collaborations.

  The selection of the 10 company cases was guided by the outcome of the literature review and it took into account some of the priority action lines as set out in the Terms of Reference of the project. In consultation with the EC it has been decided to focus on companies in the three industries with the highest R&D expenditures in Europe, in particular:

  - **Health** (Pharmaceuticals & Biotechnology, Health Care Equipment), further specified to pharmaceutical companies (we examined 3 companies)
  - **Mobility** (Automobiles & Parts, Airplanes, Public Transport), further specified to automobile companies (2 companies) and aerospace companies (2 companies).
  - **ICT** (Technology Hardware & Equipment, Electronic & Electrical Equipment, Software & Computer Services, Fixed Line Telecommunication), further specified to ICT manufacturing and software (3 companies).

  Other **key criteria** that have been taken into account for the case selection are:

  - A well balanced mix of sectors (as indicated above) taking into account the technology level: pharmaceuticals – high tech, automotive and aerospace – medium-high tech and ICT manufacturing – high tech
  - R&D intensity of the company - high R&D intensity

- Origin/nationality of companies – EU companies
- Geographical coverage (headquartered in the EU, but with dispersed GVCs)
- Company type – established MNEs and fast growing firms
- Indication of recent noticeable trends with respect to location decisions.

For each case study, we conducted around 6 interviews, so a total of 60 interviews with business representatives, company managers and industry experts have been undertaken in this study.

3. Functional and geographical fragmentation of corporate R&D&I activities

3.1. Introduction

In this chapter, we discuss the functional and geographical fragmentation of corporate R&D&I activities of companies within the 3 sectors of our investigation. For each sector we first provide a literature review on the functional and geographical fragmentation of R&D&I activities within that sector and afterwards we provide specific figures on these fragmentation patterns. Before proceeding we however first indicate in this chapter how we define R&D&I activities and how these activities can be functionally distributed.

R&D and Innovation (R&D&I)

An innovation is "*the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in internal business practices or in the open workplace*" (OECD, 2005). Given the comprehensive nature of the innovation concept, an innovative activity might include research and development but not all the research and development activities necessarily lead to an innovative outcome (such as product or process innovation). It is therefore an important yet a difficult task to delineate R&D and innovation due to the overlapping nature of concepts.

In line with the approach of the OECD Frascati Manual (2015), this study defines R&D as a "*creative and systematic work undertaken in order to increase the stock of knowledge - including knowledge of humankind, culture and society, and to devise new applications of available knowledge*". According to the OECD Frascati Manual 2015, for an activity to be an R&D activity, it must satisfy five core criteria. The activity must be novel, creative, uncertain, systematic, and transferable and/or reproducible. Innovative activities that do not satisfy these criteria can be considered as non-R&D innovation activities. These include among others design activities, staff training activities related to market introduction or product preparations, technology forecasting and product innovation. For firms not active in R&D activities, non-R&D innovation activities are among critical factors to explain how these firms achieve both production and process innovation (Barge-Gil et al., 2011; Arundel, Bordoy & Kanerva, 2008). Furthermore, Love & Roper (1999) nuance this contribution of non-R&D innovation activities by arguing that R&D expenditures explain better any innovations in products whereas non-R&D innovation activities explain better innovations in process. The most common non-R&D innovation activities are design, training, technology forecasting and innovation management.

- **Design** covers a wide range of activities, including architectural, fashion, graphic, interior, engineering and industrial design and can be implemented in a broad variety of contexts (Walsh, 1996).
- **Training** refers to improving the skills of employees and the updating of knowledge of existing staff. Training is mainly aimed at increasing the human capital and absorptive capacity of the firm (Cohen & Levinthal, 1990).
- **Technology forecasting** equals the systematic process of describing the emergence, performance, features, or impact of a technology in the coming future. Technology forecasting can take on many forms and this process could be oriented towards identifying new technological opportunities, seeking leadership in nascent technologies, looking for technology licensing, or learning more about potential technologies to develop. Technology forecasting is about anticipating

future technological development and trends and several authors have documented that it is a vital activity for the firm’s competitiveness.

- **Innovation management** refers to all activities aimed at organising the innovation process in a way that maximises market success with new processes and products (Barge-gil et al., 2011). This can take on different forms such as Human Resource Management (HRM), team-working, and co-opetition. HRM aims at stimulating employees and managers to engage in innovation activities and develop skills needed for effective innovation efforts. Team working is aimed at facilitating knowledge sharing within the team, removing organisational barriers and developing mutual trust. Co-opetition is intended at sourcing external knowledge flows by cooperating with external partners. All these mechanisms are aimed at developing organizational skills for identifying innovation ideas and as such are essential for innovation success.

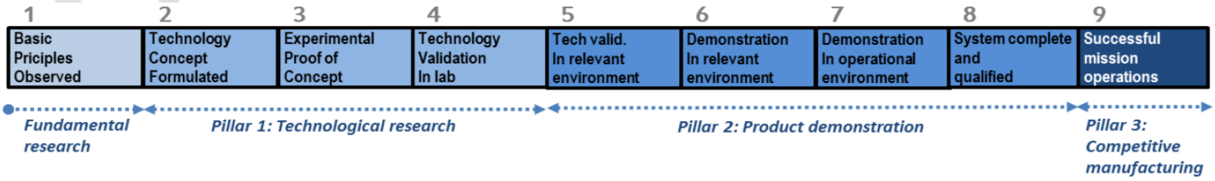
Functional description of R&D&I activities

The debate on R&D and innovation localization and organization is a complex one. Disentangling the different functions is important in order to be sufficiently precise in the discussion on R&D&I location decisions, which may affect R&D&I as a total overall function, or just a sub-activity. The location of ‘Research’ can be different than the location of ‘Development’. Depending on the type of production (routine versus non-routine), development can be more or less closely (also physically) connected to production. Simon et al. (2008) distinguish between five phases in the R&D process: research, platform development, application development, process development and production support as integrated components of a GVC functioning. These different phases however do not cover the whole R&D&I global value chain of companies. Design, validation and demonstration are for example important steps in the value chain of high tech companies.

The **Technology Readiness Level (TRL)** scale takes these tasks and functions related to innovation better into account. Initially developed during the 1970s and 1980s, Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology based on the projects progress (NASA, 2015). The scale covers gained widespread acceptance to align individual technological trajectories. Today, the TRLs scale is mainly used as a tool for facilitating the decision making process on R&D&I investments at the EU level.

The European Commission has recently adopted the TRL scale as a tool for assessing the results and expectations of technology projects. The figure below shows this TRL scale, combined with the 3 pillar bridge strategy from the European Commission.

Figure 2: TRL scale and three pillar bridge strategy from the European perspective



Source: EC, 2011; EARTO, 2014

It was decided to use the TRL scale as common denominator for the further functional description and decomposition of the R&D&I activities in this study.

3.2. Pharmaceutical sector

3.2.1. Literature study

The pharmaceutical industry is one of the most important industries of Europe. In 2015, this industry invested an estimated €31,500 million in R&D activities in Europe. Furthermore, it employs almost 725,000 people and it generates 3 to 4 times more employment indirectly (EFPIA, 2016). It is also the industry with the highest R&D intensity in the European Union (Eurostat, 2015). According to the 2016 EU R&D Scoreboard, 19% of total business R&D expenses worldwide are undertaken by the pharmaceutical and biotechnology sector. R&D expenditures are essential in the pharmaceutical industry and cover a major part of the overall innovation structure (Gassmann et al., 2002). Estimations have shown that R&D activities cover between 20 and 40% of overall costs of developed new drugs.

Traditionally, the different stages in the innovation process of pharmaceutical products have been well-documented and have a development cycle of 10 years or more (Wadhwa et al., 2008).

Figure 3 2 lists the range of activities from initial idea to final product launch by using the TRL classification.

- The first 2 stages (TRL 1 and TRL 2) concern basic research activities and in these stages research ideas and protocols are developed.
- The following 2 stages are defined as preclinical research (TRL 3 and TRL 4). An initial proof of concept (POC) will be developed and demonstrated in a number of in vitro and in vivo models. The technology will also be validated in a clearly defined laboratory setting.
- The following phase (TRL 5) will validate the technology in the relevant environment which includes tests for animal safety and toxicity. This stage has been referred to as late preclinical research.

The final 4 stages (TRL 6-9) correspond with the 4 actual trials (phase 1 – phase 4) conducted with people. The phase 1 trials typically involve a small group of healthy people and are mainly aimed at finding out how safe a particular treatment is. Phase 2 trials test the treatment in a large group of people to better measure safety and side effects and examine if the treatment has positive effects on patients. Phase 3 trials compare the effects of the newly developed treatment with a current treatment (or placebo). These trials are usually conducted with a large number of patients and accordingly are the most expensive. These trials typically account for around 30% of all R&D investments to develop a new product (PhRMA, 2014). The final phase 4 trials are carried out after the treatment has been licensed and are aimed to find out how the product/treatment works when it is widely used. Furthermore, this phase attempts to discover any long-term risks and benefits, and to pick up any possible rare side effects.

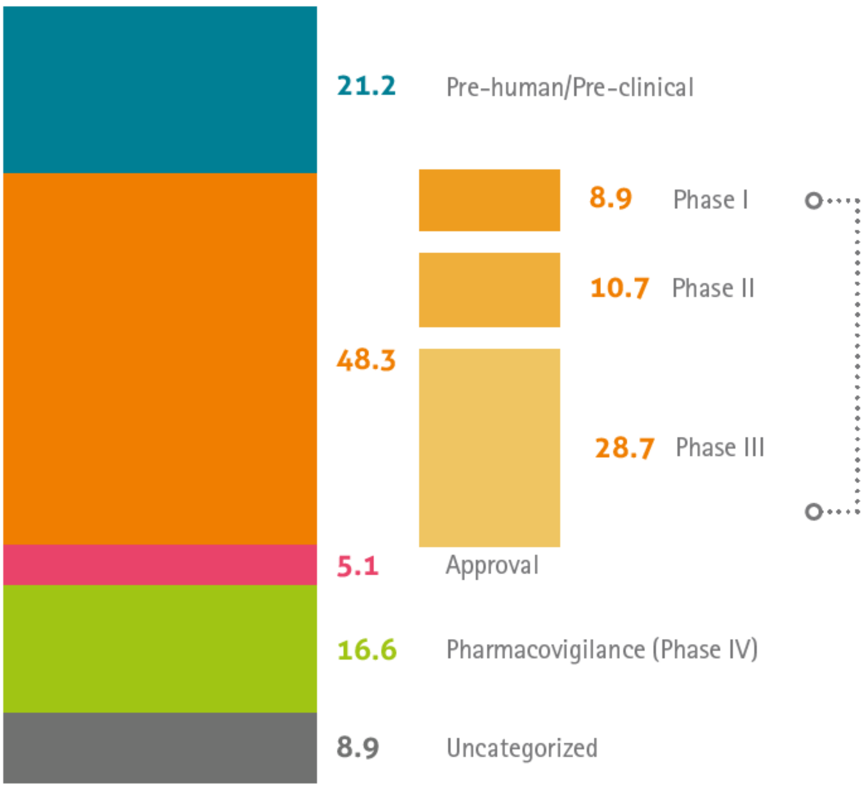
Figure 3: TRL classification of pharmaceutical R&D&I activities

TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Basic Idea	Concept developed	Experimental proof of concept	Process validated in a laboratory	Process validated on production equipment	Process capability validated on production equipment	Capability validated on economic runs	Capability validated over range of parts	Capability validated on full range of parts over long periods
Basic research		Preclinical research		Late preclinical research	Phase I trials	Phase II trials	Phase III trials	Phase IV trials
Research		Translation/Development				Commercialisation		

Source: Adopted from written evidence from Professor Chris Mason, TSB: Presentation outlining the vision for a Cell Therapy TIC, May 2011, US Department of Defence: Technology Readiness Assessment (TRA) Deskbook, July 2009, and op. cit.Strategy for Regenerative Medicine

The figure below shows how R&D expenses in the pharmaceutical industry are typically spread over the different stages of the entire process starting from pre-clinical research (TRL 3). The figure shows that the clinical trials absorb most of the R&D budget and especially the clinical trials in phase 3 (where upscaling is critical).

Figure 4: Allocation of R&D investments by function (%)



Source: PhRMA, Annual Membership Survey 2016 (percentages calculated from 2014 data, total values may be affected by rounding)

Current trends and challenges

The pharmaceutical industry has changed tremendously in the last 2 decades. More specifically, the industry has been characterized by 5 different trends:

- *Rising R&D expenditures but limited output*. R&D expenditures have increased significantly the last 2 decades (Rafols et al., 2014). The expenditures by US firms have for instance almost doubled over the period 1998-2008 (PhRMA, 2009). At the same time the output has increased.
- *Increasing costs*. Because of stricter regulations in most countries – partly deriving from uncertainty about drug safety and efficacy – costs have increased substantially (Danzon, 2006). Costs have also soared because of lengthier trials (due to the increasing focus on chronic diseases) and higher costs of product approvals.
- *The rise of emerging markets*. Emerging markets are becoming more and more important and their markets are expanding rapidly. In 2013, China was for instance already the third most important market in terms of sales numbers for Bayer Healthcare (Bayer AG, annual report 2014). The abundance of low-costs scientists in several of these countries creates additional opportunities. At the same time however, indigenous firms located in emerging markets are increasing their competitiveness and intensify global competition.
- *The rise of generics*. More recently, several of the world's best-selling drugs have lost their patent protection. When this occurs, firms no longer have the sole license to produce and sell the particular drug and generic products can enter the market. This trend has intensified global competition and increases the pressure on established firms to engage in continuous innovation.
- *Increasing complexity*. The pharmaceutical innovation process becomes increasingly complex and is more often based on an expanded set of converging technologies including biology, computational sciences, nanotechnology, and chemistry.

These trends have led to a significant restructuring of the global pharmaceutical industry. Initially, the number of pharmaceutical firms decreased over time and the industry became increasingly concentrated. Firms merged or acquired other companies to exploit economies of scope and scale and to minimize risk. However, more recently, because of soaring R&D costs and increasing competition, companies became more focused and only perform in areas in which they excel themselves, while outsourcing remaining products and processes to firms that can handle these more efficiently. To improve access to local knowledge and expertise and in order to obtain complementarities and synergies, pharmaceutical firms are also increasingly engaging in external partnerships and research collaborations. Soaring R&D costs, increasing complexity and competition, and the emergence of new geographical markets have not only led to outsourcing but also to the offshoring of R&D activities. Here below, we elaborate more on the outsourcing and offshoring trends of pharmaceutical R&D&I activities and show that these are highly dependent on the type and maturity of the R&D&I activity involved (TRL level).

Outsourcing

Performing everything in-house is not only very capital-intensive, but also risky and the opportunity costs are extremely high. Accordingly, the large established pharmaceutical companies (e.g. Pfizer, GlaxoSmithKline, Merck) aim to externalize 40%-50% of the whole R&D pipeline (Ramirez, 2014). The emergence of genomic sciences, molecular biology, technological developments in the combinatorial chemistry, and the technological development of the ICT industry have enabled the increased outsourcing of parts of the innovation process (e.g. Reddy, 2011).

In the wake of this technological revolution, new drugs increasingly originate from smaller companies, which frequently are biotechnology start-up firms (Comanor and Sherer, 2011). These small companies typically originate from academic research and emerge from technology clusters around universities and research institutes (clusters are predominantly located in the Triad regions). Large pharmaceutical companies are increasingly relying on these companies and part of the reconfiguration of their R&D value chain involves the scanning for intellectual property from smaller (biotech) firms for potential products during the various stages of the R&D pipeline. This typically ends up in mergers and acquisitions or joint-ventures with these companies. The combination of both firms can be highly synergetic; small firms specialize in discovery and enjoy the advantages of a rapidly advancing science base, while large firms have the needed expertise and resourced to demanding and highly expansive clinical trials and commercialization.

Pharmaceutical firms also increasingly rely on Contract Research Organizations (CROs) that provide research services on a contract basis. CROs provide services such as (bio)pharmaceutical development, biologic assay development, commercialization, (pre)clinical research, clinical trials management and pharmacovigilance. CROs can be highly attractive partners as they enable other firms to be more flexible and reduce costs and risks. Outsourcing to CROs can be done all along the discovery and development R&D value chain, but pharmaceutical firms make sure to not outsource the whole R&D value chain or large chunks of it, as it could endanger their competitive composition. All parts of the discovery process that require judgement, creativity, and that cannot be articulated in a "Standard Operating Procedure (SOP)" are typically not outsourced (Ramirez, 2014). Exploratory research and molecule design are also kept in-house. Other more routine R&D tasks that are well understood can be outsourced. A CRO will typically perform activities in the later phases of the R&D value chain. The traditional CROs originate from the US and the European Union, but more recently Asian CROs are gaining importance and their number has exploded exponentially. These Asian CROs however often do not have the same capabilities as their advanced country counterparts and are more engaged in the more routinized clinical trial activities. They are however also gaining ground in terms of research capabilities and are catching up rapidly (Dierks et al., 2013; Li and Zhang, 2009).

Offshoring

Traditionally, pharmaceutical companies retained their R&D activities close to headquarters and manufacturing facilities. Since the late 1990s, this has however been changed dramatically and firms started to relocate their R&D facilities away from HQ and production facilities. This relocation is mainly driven by the urge to be located close to centres of research excellence or clusters of universities and companies with advanced R&D capabilities. Tijssen (2009) documented that pharmaceutical firms' FDI investments are driven towards regions with advanced research capabilities, a specialized science base, good local universities, research institutes and science parks, and associated possibilities to tap informal R&D networks. Another study by Abramovsky et al. (2007) showed that R&D laboratories of foreign-owned pharmaceutical firms tend to be closely located to highly rated academic departments. Pharmaceutical firms want to be located close to centres of research excellence and research-intensive clusters as positive externalities (e.g. knowledge spillovers) are highly localized and research collaborations are stimulated when firms are located in close proximity. This also enables firms to recruit highly skilled people from nearby universities or other firms.

As reported by Dachs et al. (2012), the top 5 countries in terms of outward greenfield investments in the pharmaceutical industry over the period 2003-2011 are the United States, Switzerland, United Kingdom, Germany and Ireland. During that time frame, the United States is by far the dominant outward investor. US firms invested around 31% of their projects in the EU-27 member states. These investments mainly flowed to Western-European countries, as the EU-12 only received 4% of total outward US investments. In the top 10 of outward investors, India appears on place 7. India has some strong indigenous pharmaceutical firms such as Ranbaxy and Dr Reddy's laboratories and these firms are internationalizing rapidly. Other Asian countries are also gaining ground, especially in the more recent years.

3.2.2. Functional distribution of R&D&I activities

The table below shows the distribution of R&D activities across different TRLs. These estimates are based on desk research, case studies and interviews. This table shows that the clinical trials from phase 1 to phase 3 take away the largest part of the R&D budget (45-55%). Fundamental research is important for a science-based industry such as the pharmaceutical industry, but it only accounts for 10-15% of the total R&D budget in the sector.

Table 1: Distribution of R&D across TRLs

Type of activity	Priority	Share of R&D budget
Fundamental research (TRL 1-2) ***- Basic Idea*** ***- Concept development***	**3**	**10-15%**
Pre-clinical research (TRL 3-5)	**2**	**15-20%**
Clinical Trials (TRL 6-8) - Phase 1 Trials - Phase 2 trials - Phase 3 trials	**1**	**45 - 55%** *5-10%* *10-15%* *25-30%*
Pharmacovigilance (Phase 4 trials) and competitive manufacturing (TRL9)	**2**	**15-20%**

Source: estimates based on desk research, case studies and interviews

Non-R&D innovation activities, such as the management of R&D&I projects, the training of staff, technology forecasting and corporate foresight, the acquisition of machinery and equipment only account for a small fraction of the total R&D&I budget, namely around 10%. Among these activities, Design is the most important non-R&D innovation activity.

Table 2: Functional distribution of non-R&D innovation activities

Type of non-R&D innovation activity	Priority
Management of R&D&I projects	4
Staff training	3
Technology forecasting / corporate foresight	5
Acquisition of machinery and equipment	2
Design to improve/adapt existing products & processes	1

Source: estimates based on desk research, case studies and interviews

3.2.3. Geographical distribution of R&D&I activities

Within the case studies we have shown for the individual companies how their R&D&I activities are geographically distributed worldwide. Within this section, we show how these R&D&I activities for the entire sector are distributed across Europe and outside Europe.

Most R&D&I activities in the pharmaceutical sector are undertaken by companies located in Europe or the United States. To a lesser but increasing extent R&D&I activities by pharmaceutical companies are also taking place in Asia. Traditionally this was in Japan, but this is more recently shifting to China and India (especially this latter country has nurtured a more advanced pharmaceutical industry). In this section we will highlight some of the most important technological hotspots to conduct R&D&I in the pharmaceutical industry in the European Union and the United States. The selection of these hotspots or centres of excellences is mainly based on desk research, interviews undertaken for the 3 different case studies, and interviews with sector/cluster representatives, regional policy makers etc.

Locations of industrial technologies in Europe

The table below shows the top 10 countries with the highest R&D expenditures in Europe. The table also reports the production volumes of these European countries. Production is mainly based in the largest pharmaceutical markets in Europe (points to co-location of R&D with production activities) and southern countries. These countries are also home to some of the most advanced technological hotspots worldwide and count several important industry federations that defend the interests of pharmaceutical companies.

Table 3: Pharmaceutical industry R&D expenses in Europe, top 10 of countries in 2015

Country	R&D expenses in € million	Production in € million
Switzerland	6,525	42,479
Germany	6,216	29,536
United Kingdom	5,756	19,313
France	4,564	20,554
Belgium	2,589	11,232
Denmark	1,497	13,080
Italy	1,415	29,326
Sweden	1,104	7,809
Spain	908	15,213
Netherlands	642	6,180

Source: EFPIA (European Federation of Pharmaceutical Industries and Associations) – official figures, 2015
Note: the figures relate to the R&D carried out in the country.

The table below shows an over view of the locations of industrial clusters (excellence poles and clusters) across the most important European countries.

Table 4: Overview locations of technological clusters in Europe

Country	Clusters and initiatives
Switzerland	5 pharmaceutical clusters of which the Basel Region, the Lake Geneva Area and the Zurich-Zug-Lucerne are the largest ones.
Germany	Germany counts multiple medical technology clusters of which Forum MedTech Pharma e.V. (Nürnberg and München), BIOPRO Baden-Württemberg and InnovativeMedizin.NRW are the largest, healthcare industries cluster.
United Kingdom	Medcity initiative, life sciences cluster around the Golden Triangle: Oxford, London and Cambridge
France	LyonBioPole (Auverge- Rhône – Alpes) and Centre-Loire Valley.
Belgium	Biowin, healthcare cluster in Wallonia and FlandersBio in Flanders
Scandinavia	Medicon Vally, cluster organisation spread over Eastern Denmark and Southern Sweden
Italy	Toscane Life Sciences, BioMilano

Locations of industrial technologies in the United States

The US pharmaceutical market is still by far the world's most important national market in terms of sales but also in terms of R&D&I activities[3,4,5]. It is documented that in 2016 North America accounted for 49% of world pharmaceutical sales compared with 21.5% for Europe. Furthermore, according to IMS Health data (MIDAS May 2017), 64.7% of sales of new medicines launched during the period 2011-2016 were on the US market, compared with 17.5% on the European market[6]. In 2015, the US market reported close to $ 50 billion R&D expenditures in the pharmaceutical industry. Several of the global top pharmaceutical companies also have their origins in the United States. In 2016, 6 out of the top 10 companies were from the United States when based on pure pharmaceutical revenue[7]. The pharmaceutical industry in the US is clustered in a few specific regions. The table below lists the 10 regions where the industry is clustered the most.

Table 5: Top 10 US pharmaceutical clusters

San Francisco Bay Area
Boston / Cambridge, MA
San Diego
Maryland / Suburban Washington, DC
New York
Seattle
Philadelphia
Raleigh-Durham, NC (includes Research Triangle Park, NC)
Los Angeles
Chicago

Source: http://www.genengnews.com/the-lists/top-10-us-biopharma-clusters/77900061, http://blog.proclinical.com/top10-pharmaceutical-hubs-in-the-usa

3.2.4. Analysis of R&D activities on the company level based on the EU R&D Scoreboard

The pharma and biotechnology sector had a global R&D growth of 9.8% in 2016 compared to 2015. The growth by world region was: 13.2% in EU; 13% in USA: 2.3% in Japan and 27.5% in China.

The table below provides an overview of the top 20 companies in the pharma and biotech sector across the world. The top 5 of companies in term of R&D expenses are composed of two Swiss and three US companies. Large companies in the EU are Sanofi (France), Bayer and Boehringer (Germany), AstraZeneca and GlaxoSmithKline (UK), Allergan (Ireland) and Novo Nordisk (Denmark). The 9 largest R&D investors in the sector are all pharmaceutical companies (rather than biotech companies)[8].

Table 6: Overview of top 20 companies in Pharma and biotech sector (in R&D expenditures in 2015)

3 http://www.worldatlas.com/articles/countries-with-the-biggest-global-pharmaceutical-markets-in-the-world.html
4 https://www.statista.com/topics/1719/pharmaceutical-industry/
5 https://www.efpia.eu/media/219735/efpia-pharmafigures2017_statisticbroch_v04-final.pdf
6 In 2016 North America accounted for 49.0% of world pharmaceutical sales compared with 21.5% for Europe. According to IMS Health data (MIDAS May 2017), 64.7% of sales of new medicines launched during the period 2011-2016 were on the US market, compared with 17.5% on the European market (top 5 markets).
7 https://www.statista.com/statistics/281306/major-global-pharmaceutical-companies-based-on-pharma-revenue-2012/
8 The 2016 EU R&D Scoreboard

Company name	Country	Most important R&D facilities in Europe	R&D 2015 (in € million)	Employees 2015	Sales 2015 (in € million)
Novartis	Switzerland		9,002	118,700	46,282
Roche	Switzerland		8,640	91,747	44,575
Johnson and Johnson	US		8,309	127,100	64,365
Pfizer	US		7,046	97,900	44,871
Merck US*	US		6,439	68,000	36,280
Bristol-Myers SQUIBB*	US		5,291	25,000	15,211
Sanofi+	France	Germany, France	5,246	115,631	34,542
AstraZeneca*,+	UK		5,217	64,500	22,695
Bayer	Germany		4,436	116,800	47,271
GlaxoSmithKline+	UK		4,214	101,192	32,563
ABBVIE	US		3,906	28,000	20,997
Eli Lilly	US		3,663	41,275	18,333
Amgen*	US		3,620	17,900	19,897
Celgen*	US		3,396	6,971	8,502
Boehringer Sohn	Germany		3,004	0	14,798
Gilead Sciences	US		2,768	8,000	29,980
Takeda Pharmaceutical	Japan		2,637	0	13,772
Allergan	Ireland		2,460	31,200	13,843
Bioen Idec	US		1,849	7,350	9,887
Novo Nordisk+	Denmark		1,740	40,638	14,514

Source: 2016 EU R&D Scoreboard[9]

Note :

- companies with * can be classified as biotech (The 2016 EU R&D Scoreboard).
- Companies with + can be classified as biopharma (The 2016 EU R&D Scoreboard).

An important remark with respect to the top 5 companies is that, although these companies have non-EU based headquarters, important R&D activities do take place in the EU:

- Johnson and Johnson has an important R&D facility (Janssen pharmaceutical companies) in Belgium – Flanders - focussing on five strategic pathological areas: oncology, neurosciences, infectious diseases and vaccines, immunology and cardiovascular and metabolic disorders.
- Merck US, Novartis and Roche have each invested more than €2 billion R&D in the EU.
- Pfizer and Novartis have a major presence in the UK.

At the same time, large EU companies like GlaxoSmithKline and AstraZeneca reported the highest R&D outflows from the EU (mainly directed towards the US).

[9] http://iri.jrc.ec.europa.eu/scoreboard16.html

3.3. Automotive sector

3.3.1. Literature review

Within the mobility industry, we focus on the automotive and the aerospace industry. Both industries are some of the most important sectors in the EU, supporting millions of jobs, generating major added value, and investing heavily in R&D. This section focuses on the automotive sectors. Section x will illustrate the aerospace industry.

According to the European Automobile Manufacturers' Association (ACEA, 2014)[10], the European automotive industry supports 13 million jobs in Europe directly and indirectly, is responsible for €32 billion in annual R&D investment, and contributes €95.7 billion in net exports to the EU economy. Investment in research, development and innovation (R&D&I) is vital for the competitiveness of the European automotive industry. It has been documented that the European automobile industry invests €44.7 billion in R&D annually, about 5% of its total industry turnover (ACEA, 2016)[11]. At least 80% of these R&D expenditures go to product innovation, while the remaining 10-20% flow to process innovation activities (Europe Innova, 2012). Furthermore, it has been documented that only a small portion of this R&D funding is committed to conducting pure research (between 3% and 13%).

Much of R&D in the automotive industry is still based in Europe, the United States and Japan. In terms of production emerging economics are playing a bigger role. In 2016 global motor vehicle production reached a value of almost 95 million vehicles[12]. More than 30% (over 28 million units) were produced in China. China is followed by the United States (12.1 million units) and Japan (9.2 million units). The importance of China in motor vehicle production has significantly increased since 2005 (see). At the same time the role of traditional large producer companies like USA, Japan and Germany in relatively constant. The next pages will discuss if similar developments are likely to be seen in the R&D sector.

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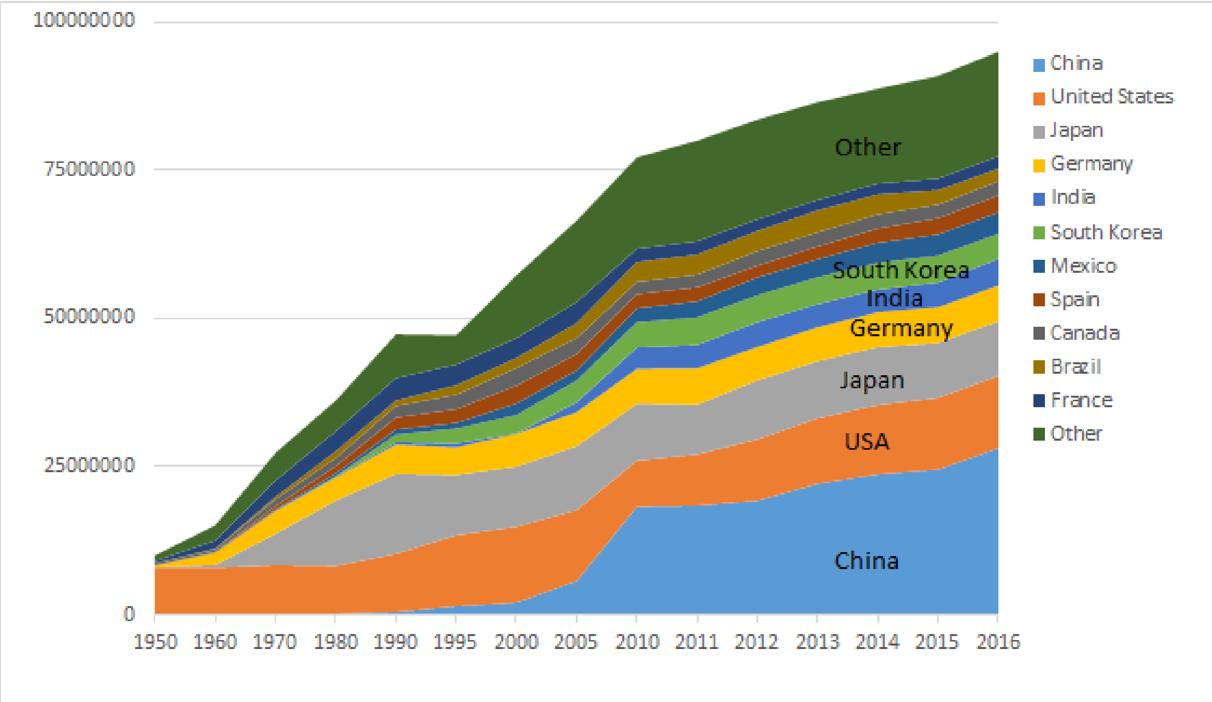
[10] ACEA (2014) - Auto industry contributes to Council discussions on EU's future climate and energy policy.

[11] ACEA (2015) - Research and Innovation. http://www.acea.be/industry-topics/tag/category/research-and-innovation

[12] Organisation Internationale des Constructeurs d'Automobiles (OICA)

Figure 5: Annual motor vehicle production by World Region (1950-2015)



Source: VDI TZ, based on data from Organisation Internationale des Constructeurs d'Automobiles (OICA)

The automotive industry has been characterised by 6 general trends and challenges in the last decade:

- *Strongly affected by the financial crisis.* The automotive industry was strongly affected by the global economic crisis. The industry suffered especially in Europe and many local firms only survived through public sector inventions (AEA, 2012). Between 2008 and 2010, absolute R&D expenditures in the industry fell by 12%, after it first increased by 35% from 2002 to 2008 (The EU R&D Scoreboard, 2016).
- *High growth in recent years.* In more recent years, the industry witnessed high growth numbers and especially in South-East Asia. Record after record has been broken in recent years (PWC, 2015). Especially the strong recovery of North America after the crisis continues to surpass expectations, while the recovery in Europe has been much slower. In South-East Asia and especially in China this growth has been tremendous in recent years. In 2013, the annual growth in production was 15% and a growth of 53% between 2013 and 2020 has been forecasted (PWC, 2015).
- *Mass customization.* In recent years, automotive firms are offering more ways to customise products and have installed different standard options for different markets. From a sales point of view, this customization presents a clear advantage, but for production and R&D, it creates tremendous challenges and increases complexity.
- *Low-cost vehicles.* Low cost vehicles are becoming increasingly important. The high value-for-money low cost brands have seen a strong growth in recent years

and it is expected that about 10% of all automobiles sold in Europe, China and India will be situated in that product group (AEA, 2012).

- *Stricter regulations.* In order to ensure the overall quality of automobiles and to make them more environmental friendly, governments have increased regulatory requirements. More specifically, regulatory requirements are getting stricter and stricter in terms of emissions, fuel efficiency, software, reliability and product safety. This necessitate further R&D investments and leads to increasing costs.
- *Connected and intelligent cars.* In the automotive industry, there is an increasing use of electronic software and a clear trend towards 'connected and intelligent cars'. In recent years, software content accounts to an increasing portion of features offered by cars. Embedded devices and software are increasingly used to expand the capabilities of cars (e.g. infotainment systems, autonomous parking and driving, etc). The so-called 'connected car' refers to a fully digitized vehicle equipped with Wi-Fi, advanced infotainment systems and apps, and vehicle-to-vehicle communication systems. The intelligent car refers to an autonomous vehicle, which can also take over control in case of danger. It is estimated that around 15% of new cars sold in 2030 could be fully autonomous (McKinsey, 2016).

These trends make that the automotive industry faces unprecedented challenges. Automotive manufacturers and suppliers are confronted with ever greater complexity caused by transforming customer expectations, shortened technology cycles, stricter regulations, increasing pressure to innovate, and global supply networks. These pressures and challenges have led to a strong outsourcing and consolidation trends. The remarkable growth in emerging markets have also led to an increasing offshoring to these markets.

3.3.2. Functional description of the R&D&I value chain

The following table gives a rough estimate of the business expenditures within the automotive sector as well as R&D personnel. During various interviews with experts from two different global companies of the automotive sector, the relevance of the different innovation activities within their business was discussed. Based on these discussions, estimated on the overall share for the different R&D activities could be made.

In a second step, based on the 2016 EU R&D Scoreboard, the sector size was estimated. For the automotive sector all companies of the sector "Automobiles & Parts" were combined.

Table 7: Decomposition of the R&D&I activities for the automotive sector

	Type of activity	Budget and share of total	Staff
R&D activities	Fundamental Research (TRL 1)	€5 - €10 billion (5 % - 10 %)	60,000 – 120,000
	Technological Research (TRL 2-4)	€15 - €22 billion (15 – 20 %)	180,000 – 250,000
	Product Demonstration (TRL 5-8)	€15 - €55 billion (15 – 50 %)	180,000 – 650,000
	Competitive Manufacturing (TRL 9)	€15 - €20 billion (~ 15 %)	150,000 – 200,000
Non-R&D innovation activities	Management of R&D&I projects	€1 - €6 billion (1 - 5 %)	10,000 – 70,000
	Staff training	€1 - €6 billion (1 - 5 %)	10,000 – 70,000
	Technology forecasting / corporate foresight	€1 - €6 billion (1 - 5 %)	10,000 – 70,000
	Acquisition of machinery and equipment	€5 - €12 billion (5 - 10 %)	n.a.
	Design to improve / adapt existing products and processes	€5 - €35 billion (5- 30 %)	50,000 – 380,000

Source: Estimation based on interviews and the 2016 EU R&D Scoreboard

3.3.3. Geographical distribution of R&D&I activities

As can be seen in Table 8 R&D expenses within the automotive sector (Manufacturing of motor vehicles, trailers and semi-trailers, ISIC 29) are highest in Japan. In 2014 they amounted to over €25 billion. With more than 122,000 R&D employees (full-time equivalents) Japan has the second highest number among all countries worldwide.

The largest number of R&D Employees worldwide is found in China with more than 200,000 people. Regarding the R&D expenses China currently ranks 3rd with €16.8 billion. Germany has R&D expenses of €19.3 billion with almost 100,000 R&D employees. The fourth important country in terms of R&D expenditures in the automotive sector are the United States (€13.8 billion). Here approximately 83,000 people work in R&D activities within the sector. Besides these four country significant R&D expenditures within the automotive sector are still found in South Korea (€5.1 billion), UK (€2.2 billion), Italy and France (€1.8 billion) and Turkey (€1 billion). Overall R&D within the automotive is highly concentrated.

One indicator that shows how R&D intensive the sector is within each country is the ratio of produced vehicles per R&D employee. Low numbers indicator a high amount of researchers relative to the production, while high numbers indicator a big production and relatively few researchers. Germany and Austria have low values with 59 and 41, respectively.

Thus, the automotive industry of these countries relatively research intensive. Low numbers are found in Spain and the Czech Republic with 541 and 341, respectively. These countries are mainly production sites.

Table 8: Business enterprise R&D expenditures for the sector "Manufacturing of motor vehicles, trailers and semi-trailers (ISIC 29)" by country, 2014

Country	R&D expenses in € million	R&D Employees (full time equivalents)	Number of manufactured motor vehicles in thousand	Ratio of Vehicles produced per R&D employee
Japan	25,174	122,080	9,774	80
Germany	19,345	99,946	5,907	59
China	16,878	211,213	23,722	112
United States	13,877	83,000[13]	11,660	140
South Korea	5,090	34,853	4,524	130
United Kingdom	2,197	12,781	1,598	125
Italy	1,793	13,040	697	53
France	1,771	12,122	1,817	150
Turkey	1,009	6,501	1,170	180
Austria	438	2,662	108	41
Spain	427	4,437	2,402	541
Czech Republic	387	3,666	1,251	341

Source: VDI TZ own calculations based on OECD.stat and OICA

Automotive clusters in Europe

Much of R&D of the automotive sector is located in *South Germany,* where companies like BMW, Daimler and Porsche/Audi (Volkswagen) have their headquarters. The largest automotive parts supplier of the world, Robert Bosch, is headquartered in this region, too. In Hessen the German headquarter of Opel (part of General Motors) is found. Another center of the European automotive industry is found at Wolfsburg in *Northwest Germany where Volkswagen, the company with the highest* R&D expenditures of all automotive companies worldwide (€13.6 billion in 2015) is located. In North Rhine-Westphalia sites of Ford and Daimler are located.

The *Paris metropolitan area* headquarters PSA (Peugeot Société Anonyme) as well as Renault. It has 3 production sites and six large R&D centres of PSA as well as Renault with around 17,500 R&D employees. A lot of automotive parts suppliers are located here as well, among them Bosch, Delphi, Denso, Johnson Controls, Faurecia, Valeo, ZF and others.

Piemonte, Italy is another European "automotive intensive" region. Particularly in the Torino area, where the Italian automotive industry was born, there exists a unique

[13] National Center for Science and Engineering Statistics (2016), https://www.nsf.gov/statistics/2017/nsf17302/nsf17302.pdf

concentration of expertise and skills. All automotive sectors are found: cars, light and heavy commercial vehicles, buses and earthmoving machines. The biggest Italian automotive company is FIAT, headquartered at Torino.

Spain is among the largest automobile producers in the world. In in all, 13 factories are located in Spain, which are supported by a vital local car components industry (Volkswagen incl. SEAT, PSA, Daimler, Ford, General Motors, Nissan, Renault).

Other large production sites are located in *England* (Nissan UK, Toyota, General Motors, (e.g. Vauxhall Motors), Jaguar Land Rover (part of Tata) and Ford. The England automotive cluster holds some important sites of premium and sports car brands such as Aston Martin, Bentley, Caterham Cars, Daimler, Jaguar, Lagonda, Land Rover, Lister Cars, Lotus, McLaren, MG, Mini, Morgan and Rolls-Royce.

The automotive industry in *Sweden* is mainly associated with passenger car manufacturer Volvo Cars. Besides that Sweden is home to two large truck manufacturers: Volvo AB and Scania AB Volvo.

While many of the above clusters have significant R&D activities, automotive clusters in *Eastern Europe* tend to be more focused on manufacturing. These clusters include the *Czech Republic, which is* as one of the leading European centres for automotive-related design and R&D activity. Besides Škoda (subsidiary of Volkswagen the truck and bus producer Tatra, the Italian truck producer Iveco and the Czech bus manufacturer SOR Libcha are located in the country as well as the Korean car producer Hyundai. *Slovakia* has been the world's largest producer of cars per capita in recent years with production plants of Volkswagen, PSA, Kia Motors as well as Jaguar Land Rover. The automobile industry in *Poland* makes up a sizeable part of the Polish economy, accounting for more than percent of countries' industrial production. Major international companies with significant presence in the Polish automotive sector include Fiat, Opel, Toyota, Volkswagen, MAN, Solaris, Volvo and Scania. In *Hungary* there exist large assembly capacities of Daimler, Suzuki, Audi and Opel in the country. An important manufacturer headquartered in *Romania* is Dacia. Many other manufacturers are found in the country like DAC, Ford Romania, Astra, DAC and Cibro and Robert Bosch.

Automotive clusters worldwide

The heart of the American automotive industry can be found at the *Detroit* metropolitan area. The Ford Motor company is the largest employer with over 44,000 employees and multiple R&D and production sites. The General Motors headquarter is found here, too. Both companies have a variety of R&D and production sites in the area. Michigan also hosts R&D sites of Daimler and Toyota. Other companies include Hyundai, Madza and Robert Bosch.

Although *California and Silicon Valley* are not traditional hotspots of the automotive industry, this has changed in recent years. Computer hardware and software as well as modern IC technology are getting more and more relevant for modern vehicles and the trend indicates that these technology will further merge together in vehicles. Google began its work on self-driving vehicles back in 2009, in 2017 Apple has begun its tests on self-driving vehicles. California is also a very relevant region for electromobility and hosts the headquarters of Tesla. Many traditional automotive companies have R&D and production activities in the region, too (e.g. Bosch, Daimler, Ford, Honda, Hyundai Kia Motors, Madza and BMW).

Japan has the highest R&D expenditures in the automotive industry worldwide, in the country has a leading role in the field of fuel cell. Most of these activities are concentrated in the Tokyo metropolitan area. The largest automotive company of the world, Toyota, is headquartered here. Honda, Nissan and Mazda have their headquarters in Japan and foreign companies like BMW, Daimler and General Motors have important facilities in the country.

In *China* joint ventures of global vehicle manufacturers with local Chinese manufacturers are very common. Volkswagen was the first foreign partner for the Chinese manufacturer First Automotive Works (FAW), but others soon followed. The eastern region (Beijing, Shanghai, Shandong byland) as well as the Guangzhou metropolitan are important automotive clusters in the country. Companies having joint ventures include Volkswagen, Hyundai, Toyota, Nissan, PSA, Daimler, BMW. Large automotive companies like Daimler, BMW, Mazda and Ford have R&D centers in the country.

India has two large automotive clusters, the Mumbai-Pune region and the Bangalore-Chennai cluster. Here sites of Skoda, Audi, Daimler, General Motors, Nissan, Renault, Ford and Hyundai are located. A lot of production activities of these companies are located in India. The R&D share of these activities is growing in the Bangalore region, which has turned into a large ICT cluster in recent years.

The south East Region of *Thailand* can be regarded as one of the most important clusters of the automotive industry with a strong focus on manufacturing engines and tires.

3.3.4. Analysis of R&D activities on the company level based on the EU R&D Scoreboard

This section gives on overview of R&D activities of the main companies in the global automotive industry. For clarity, the industry is separated into vehicle manufacturers and suppliers of automotive parts. Overall the R&D expenditures of vehicle manufactures amounted to about €80 billion in 2016. This is about 4.4 percent of the overall sales of the vehicle manufacturers that reached more than €1.7 trillion in 2015.

The Volkswagen AG had the highest R&D expenditures with over €13 billion per annum (see Figure 6). This makes up roughly 17 percent of all vehicle manufacturers' R&D expenditures worldwide. Volkswagen has several subsidiaries worldwide, among them Audi, MAN, Porsche, SEAT, Skoda and Lamborghini, most of them operating worldwide. At R&D intensity at Volkswagen is relatively high with 4.9 percent, the sales amount to €213 billion, and the second largest sales of all vehicle manufacturers worldwide. The headquarters of Volkswagen is found at Wolfsburg, Germany. The top position in the industry is held by Toyota motor company with sales of €216 billion. R&D expenditures at Toyota amount to €8 billion, the R&D intensity is 4 percent. Toyota is headquartered in the city of Toyota, Japan. The company holds the subsidiaries Daihatsu and Hino and the business unit Lexus.

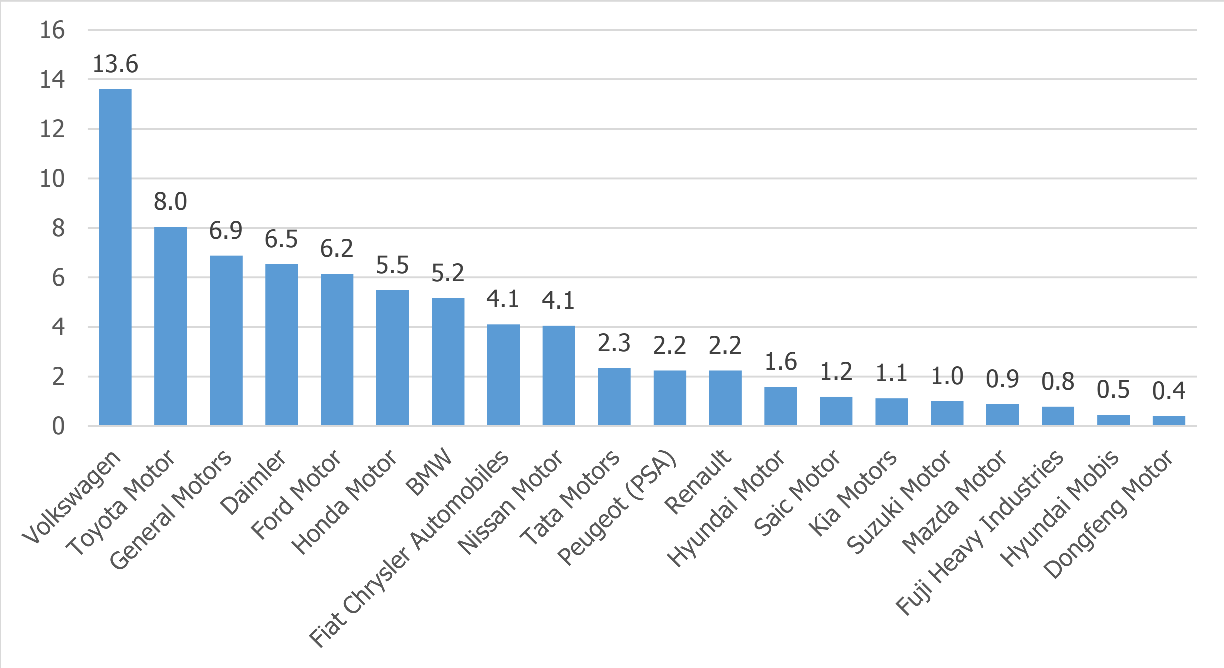
General Motors is found at the third position with R&D expenditures of €6.9 billion. The R&D intensity is relatively low with only 2.6 percent. Sales amount to roughly €140 billion. General Motors is headquartered in Detroit, Michigan, USA. The company has several business units, among them Cadillac, Chevrolet, JieFang, Opel Holden,and UzDaewoo. Some like JieFang and SAIC-GM focus on the Chinese market, Opel focuses on the German market, Holden addresses Australian customers and UzDaewoo Russian and Central Asian markets.

Daimler is found at the fourth position with R&D expenditures of €6.5 billion. In differences to Toyota, Volkswagen and General motors, who all manufactured more than

7 million vehicles per annum each, the number of manufactured vehicles is much smaller for Daimler (about 2.1 million). Still the amount of sales is equally high with almost €150 billion. The main reason for this is that Daimler has a stronger focus on trucks and other commercial (including military) vehicles. Daimler's R&D intensity is relatively high for the industry (4.7 percent). Daimler is followed by Ford (€6.2 billion), Honda (€5.5 billion, BMW (€5.2 billion), Fiat Chrysler (€4.1 billion) and Nissan (€4.1 billion). All of the large vehicle manufacturers have their headquarters located in Europe, the United States or Japan. The most relevant companies regarding R&D outside of these regions are Hyundai (Korea) and SAIC (China).

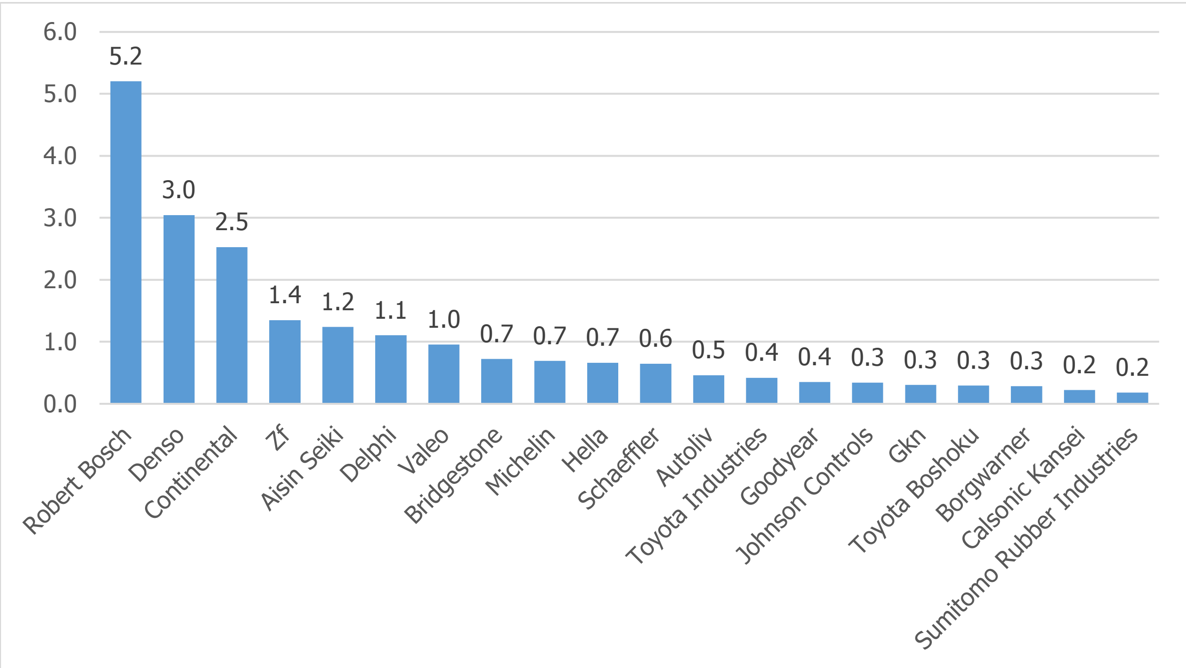
Compared to vehicle manufacturers automotive parts suppliers are more compartmentalized. All automotive parts suppliers among the top 2500 companies worldwide have more than €30 billion of R&D expenditures and over €650 billion of sales. Robert Bosch is by far the largest automotive parts supplier worldwide. The company's products range from automotive components, including brakes, controls, electrical drives, electronics, fuel systems, generators, starter motors and steering systems to industrial products like drives and controls as well as building products (e.g. power tools, security systems). The company has R&D expenditures of more than €5.2 billion euros and an R&D intensity of 7.4 percent. Bosch is one of the main suppliers of companies like Volkswagen and Daimler. Another large automotive parts manufacturer is Denso, headquartered in Japan. Denso is closely tied to Toyota which is responsible for almost 50 percent of the sales. Continental has R&D expenditures of €2.5 billion. The German company is specialized on tyres, brake systems, interior electronics, automotive safety, powertrain and chassis components and tachographs. Other large automotive parts suppliers with annual R&D expenditures above €1 billion include ZF (Germany), Aisin Seiki (Japan), Delphi (UK) and Valeo (France). R&D intensity of the larger automotive parts suppliers is generally above 6 percent (see Figure 7).

Figure 6: R&D expenditures of vehicle manufacturers, in € billion, top 20 companies in 2015/2016



Source: VDI TZ, based on the 2016 EU R&D Scoreboard

Figure 7: R&D expenditures of automotive parts suppliers, in € billion, top 20 companies in 2015/2016



Source: VDI TZ, based on the 2016 R&D Scoreboard

3.4. Aerospace sector

3.4.1. Literature review

In 2014, the aerospace industry employed more than 795,000 people and generated a turnover of €199.4 billion (ASD, 2015)[14]. In the aerospace industry, R&D expenditures are between 11% and 21% of industry turnover (dependent on the countries included in the sample, this is between 3 and 6 times higher than the average reported by all manufacturing firms (Europe Innova, 2012)).

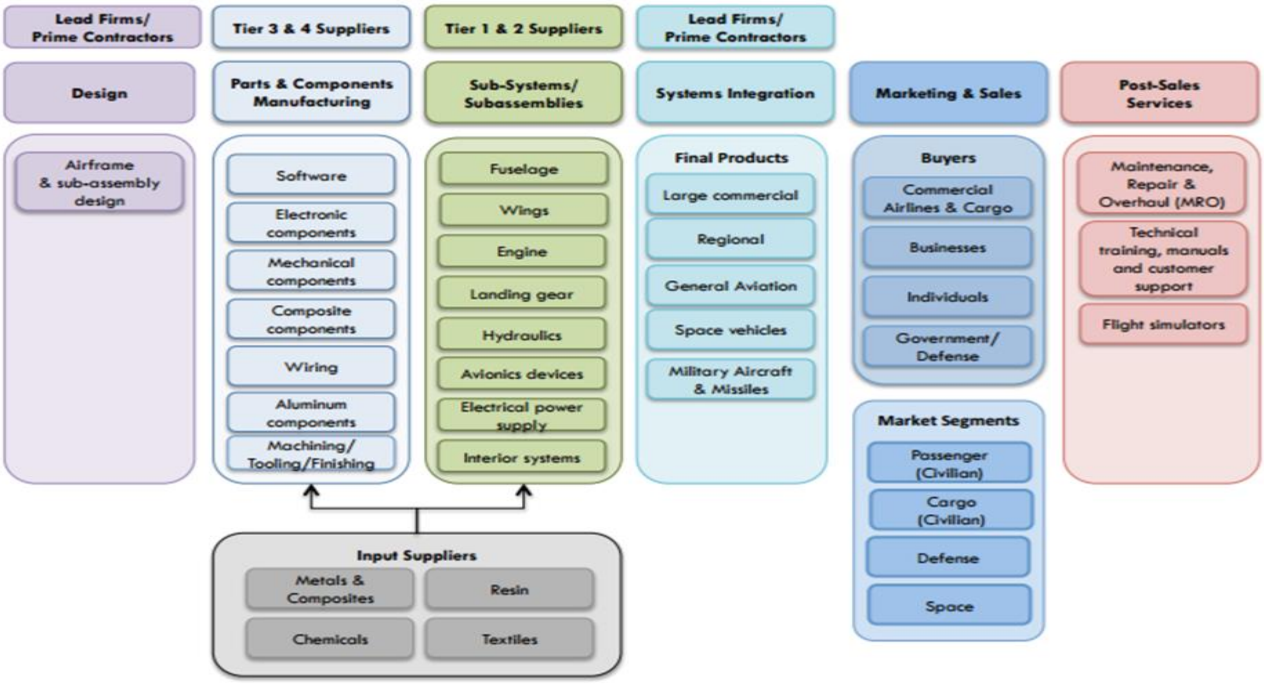
The figure below provides a visual representation of the aerospace global value chain, especially focused on aircraft manufacturing. Manufacturing an aircraft requires 4 stages: design, parts & components manufacturing, subassembly and systems integration. Sales, post-sales services and marketing activities are also important.

The manufacturing process in the aerospace sector has several phases[15]:

- **Design:** the expenses required for the product design and R&D are enormous in the aeronautics and space industry. Concerning the time horizon, between five and ten years are necessary for the development of a product and the return to investment is only positive after ten to eighteen years.
- **Parts and components manufacturing**: this phase concerns the entirety of general and specific inputs necessary to the formation of aircraft subassemblies. Companies which develop product-specific and industry-specific parts usually dominate this segment of the chain.
- **Sub-assemblies or sub-systems**: the final assembly line is composed of sub-assembly modules. Those can be propulsion engines, avionics, and airframe and so on.
- **Systems integration**: this phase of the value chain concerns the gathering and connecting of all systems and subsystems to the aircraft in order for it to become a complete system.
- **Final products and end** market segments: commercial aircrafts, regional jets, spacecraft and military aircraft are all types of final products from the aerospace value chain. The target market consequently includes passenger, cargo, defence and space segments.
- **Post-sales services:** after the supply of an aircraft, the manufacturing company is still responsible for maintenance, technical assistance, training, customer support and overhaul. The training is necessary for pilots, crew, and maintenance workforce.

[14] ASD (2015) - About us. http://www.asd-europe.org/home/
[15] Duke Centre on Globalization, Governance & Competitiveness (2013). Costa Rica in the Aerospace Global Value Chain: Opportunities for Upgrading", available on http://www.cggc.duke.edu/pdfs/2013_08_20_Ch4_Aerospace.pdf

Figure 8: Aerospace Global Value Chain



Source: Duke Centre on Globalization, Governance & Competitiveness (2013). Costa Rica in the Aerospace Global Value Chain: Opportunities for Upgrading", available on http://www.cggc.duke.edu/pdfs/2013_08_20_Ch4_Aerospace.pdf

3.4.2. Functional distribution of R&D&I activities

With regards to the functional distribution of R&D activities, and show approximate figures on how the R&D budget is distributed across TRLs and R&D activities in large aerospace companies. Interviews confirm that most of the activities are done in demonstration phase. Fundamental research represents a very small share of the budget and it is carried out mostly in collaboration with external partners (universities, research centres, etc.). Non-R&D innovation activities, such as the management of R&D&I projects, the training of staff, technology forecasting and corporate foresight, the acquisition of machinery and equipment constitute a small fraction of the R&D budget: around 10% of the total according to the interviewees.

Table 9: Distribution of R&D budget across TRLs

Type of activity	Priority	Share of R&D&I budget
Fundamental research (TRL 1)	4	Between 5-10%
Technological research (TRL 2-4)	2	25-35%
Product demonstration (TRL 5-8)	1	60-70%
Competitive manufacturing (TRL 9)	3	Between 5-10%

Source: Interviews

Table 10: Distribution of budget across R&D activities

Type of activity	Share of R&D&I budget
R&D activities (across TRLs)	90%
Other innovative activities, such as — Management of R&D&I projects, — Staff training — Technology forecasting / corporate foresight — Acquisition of machinery and equipment — Design to improve/adapt existing products & processes	10%

Source: Interviews

3.4.3. Geographical distribution of R&D&I activities

Within the case studies we have shown for the individual companies how their R&D&I activities are geographically distributed worldwide. Within this section, we show how these R&D&I activities for the entire sector are distributed across Europe and outside Europe.

Locations of industrial technologies in Europe

The European aerospace landscape is characterized by the existence of strong industrial areas focusing on this sector. Most of these areas are led by the existence of a facility of one of the large aircraft manufacturers – e.g. Leonardo, Airbus, etc. – and around which a varied environment is developed. The countries where the aerospace sector has the strongest presence are France, Germany, Italy, UK, and Spain. A brief overview of locations of technological clusters in the aerospace sector across these European countries is provide in the table below .

Table 11: Overview locations of technological clusters in Europe

Country	Clusters and initiatives
United Kingdom	Main locations in the UK are South East England, Birmingham and Scotland. Some of the largest cluster initiatives are the ADS group, (mainly located in South-East England), Space Network Scotland, and Scottish Centre of Excellence in Satellite Applications
France	The largest presence of the aerospace ecosystem can be found around three innovation clusters: Aerospace Valley (Occitanie and Nouvelle-Aquitaine regions), Astech (Ile de France/Paris region) and Pegase (Provence-Alpes-Côte d'Azur).
Germany	Largest clusters are around Bayern (bavAIRia) and Hamburg (Hamburg Aviation)
Italy	The largest presence of the aerospace industry in Italy is found in six regions: Lombardy, Lazio, Piedmont, Campania, Apulia and Umbria. Piedmont and Lombardy (15,000 and 15,800 employees respectively) have the most extensive capabilities, although Lombardy has a more relevant presence of the helicopter industry. The industry in Lazio focuses space segment. Apulia and Campania specialize on aerostructures. The Italian Cluster for Aerospace Technology (CTNA) is the best known cluster initiative in Italy and gathers all the main actors in the sector (e.g. regional aerospace industrial and technological districts, industry federations and large enterprises).
Spain	In Spain, the aerospace sector is mainly clustered in Sevilla, Madrid, Castilla la Mancha, and Cadiz. Two major aerospace clusters in Spain are HEGAN, the Basque Aerospace Cluster (Vizcaya, central location in the Basque Country) and the Hélice cluster, located in Sevilla, Andalusia.

Locations of industrial technologies outside Europe

United States

The aerospace industry in the United States is largely dependent upon the activity carried out by the Boeing Company. In 2017 largest numbers of employees working at Boeing are found in Washington (24,642 employees), in Missouri (14,053 employees), and in California (13,211 employees). In Washington, the aerospace cluster is largely driven by Boeing: the final assembly facilities for the 737, 747, 767, 777, 787, and the P-8 and KC-46 military aircraft are located in this State. This entails that the company also supports the development of an extensive ecosystem that covers many parts of the aerospace supply chain. In addition, Washington is also home to a number of space-related companies (Aerojet Rocketdyne, Blue Origin, Planetary Resources, SpaceX, etc.)

Brazil

Brazil is the home country of Embraer, one of the largest regional jet producers worldwide, in close competition over similar products with the Canadian company Bombardier. A 2011 report indicates that approximately 350 companies operate in the aeronautics sector in Brazil, of which 50 are final manufacturers and first-tier suppliers that employ 23,000 people[16]. This report claimed that most of the companies are spin-out companies created by former employees of Embraer. Interestingly, 98% of Embraer's

[16] Fernandes, et al (2011). Brazil- Aeronautics Cluster. Harvard Business School. Available at: http://pakaero.com.pk/index.php/brazil-aerospace-cluster/

first-tier suppliers come from other countries and there is a significant presence of foreign-owned companies in Brazil cluster (e.g. the Spanish company Aeronnova). The State of Sao Paulo has the largest aerospace industry in the region. The Technological Institute of Aeronautics located in this State and led by the Ministry of Defence, provides technology service to the industry.

Canada

The aerospace sector in Canada contributes with $28 billion to the country´s GDP and supports 211,000 jobs[17]. When looking into the direct employment in the sector, figures of the aerospace association show that engineers, scientists and technicians constitute 33% of the workforce, while production workers are 47% and the rest other types of employees (management, administration, etc.). This shows the relevance of R&D in this sector in Canada: 29% of the R&D in manufacturing is done in this sector. More than half of the employees in aerospace manufacturing are located in Quebec (55%), followed by Ontario (24%).

3.4.4. Analysis of R&D activities on the company level based on the EU R&D scoreboard

The aerospace sector had a global R&D growth of 1.2% in 2016 compared to 2015. The growth rates reported per world region however varied significantly. The growth by world region was -0.8% in the EU; 2.8% in the USA: 2.0% in Japan and a remarkable 44.7% in China. The average R&D intensity was 4.3% worldwide and here the EU reported the highest R&D intensity – compared to USA, Japan and China – of 5.4%. The country that reported the highest R&D increase in 2016 compared to 2015 was Germany with 6.8%.

The table below provides an overview of the top 20 companies in the aerospace and defence sector worldwide. The top 5 of companies in terms of R&D expenditures are composed of one Dutch company, two US companies, one Canadian, one Italian and one French company. Within the top 20, the US accounts for the most companies, which is 7. The top 20 accounts for €18.6 billion R&D expenditures and employs more than 1.24 million employees in 2015. Table 12 provides an overview of the top 20 companies in terms of R&D expenditures worldwide. Airbus (Netherlands) is clearly the largest player with €3.614 billion R&D expenditures and 136,574 employees in 2015. Other important players are Leonardo (Italy), Safran (France), Rolls-Royce (UK), Thales (France), Dassault Aviation (France), Zodiac Aerospace (France), BAE Systems (UK), SAAB (Sweden) and Cobham (UK).

[17] The figures of this section are shown in: AIAC (2016) State of Canada´s Aerospace Industry. 2016 Report. Innovation, Science and Economic Development Canada. Available at: http://aiac.ca/wp-content/uploads/2016/06/State-of-Canadas-Aerospace-Industry-2016-Report.pdf

Table 12: Overview of top 20 companies in aerospace and defence, worldwide

World rank	Company name	Country	R&D 2015 (in € million)	Employees 2015	Sales 2015 (in € million)
38	AIRBUS	The Netherlands	3,614	136,574	64,450
45	BOEING	US	2,796.915	161,400	88,283.31
61	UNITED TECHNOLOGIES	US	2,231.102	197,000	51,527.53
80	BOMBARDIER	Canada	1,647.838	66,950	16,691.47
99	LEONARDO - FINMECCANICA	Italy	1,373	47,156	12,995
114	SAFRAN	France	1,191	70,087	18,100
137	ROLLS-ROYCE	UK	1,003.179	50,500	18,682
172	LOCKHEED MARTIN	US	770.6442	126,000	42,373.49
184	TEXTRON	US	714.614	35,000	12,329.39
232	THALES	France	553.5	61,848	14,063.2
284	EMBRAER	Brazil	405.8971	0	4,776.324
287	DASSAULT AVIATION	France	404.238	11,984	4,175.805
322	GENERAL DYNAMICS	US	362.8182	99,900	28,905.13
349	ZODIAC AEROSPACE	France	334.199	32,388	4,931.754
418	BE AEROSPACE	US	252.0438	10,057	2,507.211
422	ROCKWELL COLLINS	US	249.8394	19,500	4,816.756
434	BAE SYSTEMS	UK	245.0099	75,000	22,849.89
467	ELBIT SYSTEMS	Israel	223.5842	12,134	2,854.397
524	SAAB	Sweden	192.1759	14,685	2,958.378
538	COBHAM	UK	187.8409	12,527	2,820.336

Source: The 2016 EU R&D scoreboard

3.5. ICT sector

3.5.1. Literature review

In 2010, the ICT sector value added amounted to €496 billion, representing about 4.0% of the EU GDP. In 2010, the five largest economies were also the five biggest contributors to the value added of the ICT sector: Germany, France and the United Kingdom (€82-83 billion and 16-17%), Italy (€58 billion and 11.6%) and Spain (€37 billion and 7.4%). Together, those five countries represented 69% of the total European value added of the ICT sector in 2010. Also in 2010, the ICT sector employed about 6.0 million people, with more than 4.0 million people in the ICT services segment, about 1.0

million people in the telecommunications segment and the remaining 1.0 million in the ICT manufacturing industries and the communication equipment segment.[18]

ICT generates 25% of total business expenditure in Research and Development (R&D), and investments in ICT account for 50% of all European productivity growth. EU investments in ICTs are due to increase by about 25% under Horizon 2020 compared to FP7. This EU investment will support the whole chain from basic research to innovation that can deliver new business breakthroughs, often on the basis of emerging technologies.[19] In most OECD countries, the ICT sector accounts for the largest share of business expenditures on research and development (BERD), amounting to almost 33% of total BERD and 0.5% of GDP in most countries.

Overall, ICT industry and ICT-enabled innovation in non-ICT industries and services make an important contribution to economic growth of advanced economies. In the EU, the USA and Japan, the ICT sector is by far the largest R&D-investing sector of the economy. The EU ICT sector is therefore a significant contributor to the ambition of achieving the target of investing 3% of GDP in R&D in the EU. But, when comparing ICT expenditures over GDP, the USA, Japan, and also Taiwan and Korea, are investing significantly more in ICT R&D than the EU. ICT is a strongly internationalized sector, especially in ICT goods and – to a lower extent – in ICT services. In addition, the use of ICT is facilitating and stimulating internationalization of non-ICT sectors, ICT facilitates both fragmentation as well as international outsourcing.

The ICT industry, as a relatively "new" industry, still shows constant dramatic changes every decade. In recent years, the following trends have been pointed out by the literature in particular:

- *Shift to the ICT world market to emerging economies:* In 2009 the share of the ICT world market in OECD countries declined to 76% from 84% in 2003, as growth in non-OECD economies became relatively independent from growth in OECD countries (OECD, 2010). As part of this shift the top 250 ICT firms include more non-OECD firms, among them manufacturing firms in Chinese Taipei, which have partly driven the rise of China as the major exporter of ICT goods, IT services firms from India, and telecommunication services providers from a range of non-OECD economies.
- *Trade in ICT services is growing faster than trade in ICT goods:* Between 2001 and 2013, the world exports of manufactured ICT goods grew by 6% annually, reaching over 1.6 trillion US dollars in 2013 (OECD, 2015). Simultaneously, the share of computers and peripherals in total ICT world exports decreased by 11 percentage points, as a result of widespread prices and inelastic demand curves. This may indicate a major shift in world trade patterns towards communication equipment and electronic components.
- *Regional concentration of production and export of ICT goods:* Production and export of ICT goods are increasingly concentrated in a few economies, in particular China, Korea, Singapore, United States, Taiwan, but also Germany and the Netherlands. In particular, 25% of all ICT R&D centres are located in the EU and around 30% in the US, 16% in Japan 16% and 22% in other Asian countries,

[18] European Commission (2014) – Digital Agenda Scoreboard: The EU ICT Sector and its R&D Performance

[19] European Commission - ICT Research & Innovation. https://ec.europa.eu/programmes/horizon2020/en/area/ict-research-innovation.

especially China. Most firms still locate most of their R&D activities in their home country. Despite the existence of strong linkages between Japan, the US and the EU, Asia, in particular, is very attractive as a location for R&D centres for international ICT companies.

- *Increasing role of the ICT sector in innovation activities:* Out of total business enterprise expenditure (BERD), business in 2013, R&D performed by the ICT sector accounted for almost 0.5% of GDP (OECD, 2015). While R&D provides a measure of innovation input, patents, registered designs and trademarks capture innovation output. Patent applications in ICT technologies accounted for almost 40% of total applications. Although the number of international ICT patents has steadily increased during the past decades, the level of international collaboration output remains very low (Nepelski and De Prato ,2012)
- *Increasing demand for ICT specialists across all sectors:* Overall, the contribution of the ICT sector to total employment growth has varied significantly over the past 15 years, but remained stable, in sum. At the same time employment of ICT specialists across all sectors of the economy has risen, reaching at least 3% of total employment in most OECD countries. This indicates the employment of the ICT sector is shifting more towards high-skilled.
- *Challenges of traditional security approaches in a global data-intensive environment:* Data-driven innovation along GVC relies greatly on the quality of the digital environment. It must be open and interconnected, as well as flexible and host a massive volume of data of considerable diversity. These interrelated characteristics increase the complexity of security management to a point where the traditional security approach cannot scale up (OECD, 2015b). Cybercrime (such as hacking, industry espionage, and cyberbullying) is an increasing issue for companies of the ICT and other sectors. While GVC are international, a lot of laws to prevent cybercrime are still applicable only on the national level and international agreements are reached only slowly. Recent trends such as cloud computing, mobility, "bring your own device", machine-to-machine communication (M2M) and the "Internet of Things" will further dissolve of boundaries for information systems and networks and hence the vulnerability of businesses and individuals.

3.5.2. Functional description of the R&D&I value chain

The following table gives a rough estimate of the business expenditures within the ICT sector as well as R&D personnel. During various interviews with experts from two different global companies of the ICT sector, the relevance of the different innovation activities within their business was discussed. Based on these discussions, estimated on the overall share for the different R&D activities could be made.

In a second step, based on the 2016 EU R&D Scoreboard, the sector size was estimated. For the ICT sector all companies of the sectors "Electronic & Electrical equipment", "Technology Hardware & Equipment", " "Software & Computer Services", "Fixed Line Telecommunications", "Mobile Telecommunications" were combined.

Table 13: Decomposition of the R&D&I activities for the ICT sector

	Type of activity	Budget and share of total	Staff
R&D activities	Fundamental Research (TRL 1)	€2 - €30 billion (1 % - 10 %)	30,000 – 350,000
	Technological Research (TRL 2-4)	€70 - €120 billion (30 – 45 %)	1 – 1,5 million
	Product Demonstration (TRL 5-8)	€35 - €120 billion (15 – 45 %)	0,5 – 1,5 million
	Competitive Manufacturing (TRL 9)	€5 - €50 billion (5 – 20 %)	50,000 – 700,000
Non-R&D innovation activities	Management of R&D&I projects	€10 - €30 billion (5 - 10 %)	150,000 – 350,000
	Staff training	€1 - €30 billion (1 - 10 %)	30,000 – 350,000
	Technology forecasting / corporate foresight	€1 - €10 billion (1 - 3 %)	30,000 – 120,000
	Acquisition of machinery and equipment	€5 - €70 billion (3 - 20 %)	n.a.
	Design to improve / adapt existing products and processes	€2 - €12 billion (1- 4 %)	30,000 – 150,000

Source: Estimation based on interviews and the 2016 EU R&D Scoreboard

3.5.3. Geographical distribution of R&D&I activities

R&D expenditures by country

This section investigates which regions worldwide are the most relevant for the ICT sector. It looks at R&D statistics on the company level and regional level. European as well as international clusters in America and Asia are considered.

As can be seen R&D expenses within the core industries of the ICT sector (Manufacture of computer, electronic and optical products, ISIC 26; Telecommunications, ISIC 61; Computer programming, consultancy and related activities, ISIC 62) are highest in the United States. In 2014 they amounted to more than €65 billion (see Table 14). With more than 330,000 R&D employees (full-time equivalents, the United States has the second highest number among all countries worldwide.

The largest number of R&D Employees worldwide is found in China with more than 550,000 people. Regarding the R&D expenses China currently ranks second with €49.2 billion. Apart from China and USA three Asian economies dominate R&D in the ICT sector: Japan, South Korea and Taiwan. R&D expenditures in the ICT sector in Japan amount to €30.7 billion, in Korea to €26.5 billion and in Taiwan to €18.2 billion. Japan has almost 180,000 R&D employees in the ICT sectors, followed by Taiwan (over 130,000) and Korea (over 115,000).

Within Europe Germany has the highest R&D expenditures in the ICT sector, they amount to more than €10 billion with almost 80,000 R&D employees. The second important country in terms of R&D expenditures in the European ICT industry is France (€5.5 billion). Here approximately more than 55,000 people work in R&D activities within the sector. Besides these two European economies significant R&D expenditures in Europe are still found in the United Kingdom (€3.7 billion) and Italy UK (€2.5 billion). Israel with over €4 billion R&D expenditures in the ICT sector and Canada (almost €1.5

billion) are relevant regions, too.

From the table below it can be seen that the United States dominate R&D in the "Computer programming, consultancy and related activities" subsector, followed by Israel and Germany. In contrast, within the "Manufacture of computer, electronic and optical products" subsector, the USA dominate R&D together with Asian countries (China, Japan, Korea and Taiwan.". India is currently not included in the OECD figures. Due to lack of comparability the country is not included in the tables. In previous years, India's R&D figures[20] were still significantly lower than in the top ICT countries mentioned above. However, by 2017 it is very likely that the country has catched up significantly and will certainly play a role of R&D in the ICT sector in the future.

[20] http://is.jrc.ec.europa.eu/pages/ISG/PREDICT2014compnonEU.html

Table 14: Business enterprise R&D expenditures for ICT industries (ISIC 26, 61, 62) by country, 2014

Country	R&D expenses in € million			
	Manufacture of computer, electronic and optical products	Telecommuni-cations	Computer programming, consultancy and related activities	Sum
United States	55,714	2,831	8,308	66,853
China	46,600	890	1,787	49,277
Japan	25,352	3,337	2,045	30,734
South Korea	25,983	382	222	26,586
Taiwan	17,337	222	643	18,203
Germany	7,384	375	2,678	10,436
France	3,407	558	1,573	5,537
Israel	1,228	n. a.	2,898	4,126
United Kingdom	1,096	867	1,781	3,744
Italy	1,345	320	883	2,548
Canada	1,367	256	857	2,480
Sweden	1,537	n. a.	336	1,873

Source: VDI TZ own calculations based on OECD.stat and OICA

ICT clusters in Europe

One of the ICT hotspots in Europe is *England*. This region is characterized by the "M4 corridor", "Silicon Fen", "Silicon Roundabout" as well as the "Oxford Science Park". Important global players of Silicon Fen include Cisco, Microsoft, ING Direct, Oracle, Prudential, Yell Group, Vodafone and Ericsson. "Silicon Roundabout" is one of the largest technology startup cluster in the world. The startups greatly benefit from a variety of global ICT global players, among them Facebook and Alphabet that have their European headquarted located here.

The "*Isar Valley*" in South Germany hosts several important global companies of the ICT sector, especially in semiconductors, telecommunication and electronic parts and systems. Companies present in the area include Brainlab, Cancom, Fujitsu, Gigaset, Infineon, Kontron, NorCom, Siemens, Telefónica and Wirecard. Other ICT clusters found in Germany are *Silicon Saxony* and *Silicon Allee (Berlin).*

Paris-Saclay in France is currently developing towards a research-intensive business cluster. It encompasses research facilities, universities and other higher education institutions ("grandes écoles") as well as R&D centers of private companies, among them the large French telecom companies Orange S.A. and Numericable-SFR. *Sophia Antipolis* is another, smaller French ICT cluster and technology park.

Kista near *Stockholm* headquarters the large multinational networking and telecommunications equipment and services company Ericsson. Nokia's headquarters are found in Espoo within the *Helsinki* metropolitan area. The business of Nokia with mobile devices has suffered in recent years from competition with other international companies (e.g. Apple).

Being one of the most wired countries in the world, the *Netherlands* are another European hotspot for ICT companies. The Netherlands host sites of Microsoft, Cisco, Interxion, Infosys, Huawei, Oracle, Intel, IBM, Verizon as well as Alphabet. The region provides a powerful IT-infrastructure, a competitive tax climate and a tech-savvy, English-speaking workforce. Besides that several companies of the global gaming industry are found here: Guerrilla Games, Perfect World, Kixeye and Activision Blizzard. In addition, a large security cluster and one of the most advanced European markets of data centers is located in the Netherlands.

Taguspark is a science and technology park located at Oeiras within the *Lisbon* region, Portugal. It accommodates several R&D labs, startups and business incubators, especially in the ICT sector (e.g. Portugal Telecom).

ICT clusters worldwide

By far the largest and most famous ICT cluster in the world is *Silicon Valley*, located at the San Jose metropolitan area in California, USA. Nowadays it is closely connected to the *San Francisco* ICT cluster. Many thousands high tech companies are headquartered in this region, several thousand of other companies have sites in the region. The largest among them are Apple, Intel, Alphabet, Oracle, Facebook, HP Inc. and Qualcomm. The ICT-ecosystem of Silicon Valley includes offices of EMC, Samsung, Fairchild Semiconductor/Cypress Semiconductor, Infineon, Mitsubishi Electric, Siemens, SAP. Samsung, Microsoft, Amazon, Dell and many others. Large research centres can be found here, among them the IBM Almaden Research Center, Samsung Research America and the NASA Ames Research Center.

"The Dulles Technology Corridor", sometimes called "The Silicon Valley of the East" is another ICT cluster within the United States. It is located at located in *Northern Virginia* near Washington Dulles International Airport. Many medium-sized ICT companies are headquartered here. Among them, CACI International , Carahsoft, DXC Technology, DLT Solutions, MicroStrategy, Network Solutions, Neustar and XO Communications. The ICT companies often have close cooperation with companies of the airline, defense and security industry, among them Northrop Grumman, Orbital ATK, General Dynamics have their headquarters located in the Dulles Technology Corridor.

Silicon Alley, centered in Manhattan is home to New York metropolitan region's high tech industries. Relevant industries include the Internet, new media, telecommunications, digital media, software development, game design and the financial technology (fintech) industry, which benefits from the close proximity Wall Street.

The ICT cluster at *Bangalore*, also called the "Silicon Valley of India" is probably the fastest growing ICT cluster worldwide. If the growth continues, Bangalore could surpass Silicon Valley as the world's IT capital in some years, especially regarding the number of high-skilled employees. In 2015, Bangalore contributed to almost 40 per cent of India's total IT exports. Many international ITC companies are found here, among them 3M, HP and Siemens. Infosys and Wipro. The Whitefield cluster is hosts the International Tech Park Bangalore. The area provides campus facilities for SAP, Xerox, iGATE, Dell, TCS, Unisys, Delphi, Huawei, Oracle and Perot Systems.

Tsukuba Science City in the Tokyo metropolitan area benefits from the largest budget of government-sponsored general R&D for any science park zone of its size worldwide. The academic landscape is powerful here: universities include the University of Tsukuba, National University Corporation Tsukuba University of Technology, Tsukuba Gakuin

University, Graduate University for Advanced Studies and the Tsukuba Campus. Many multinational companies perform R&D in this region. These include Intel Japan, Hitachi, Canon and many others.

Suwon at Korea is home to the largest ICT-company of the world (with respect to R&D expenditures): Samsung. The area is also called "Samsung Digital City". It is the dominant place in the world for chip memory and integrated system on a chip with large components of microchip memory. LG is also headquartered in the area.

The *Guangdong* region with the Shenzhen Hi-Tech Industrial Park can be considered China's ICT hotspot. Electronics, information technology, biology, optical-electrical-mechanical integration, pharmaceuticals and other High-tech industries are the major industries in Shenzhen.

The *Hsinchu Science Park* at Hsinchu City in *Taiwan* is the dominant place worldwide for pure-play semiconductor foundry market. The area is home to the world's top two semiconductor foundries: Taiwan Semiconductor Manufacturing Company (TSMC) and United Microelectronics Corporation (UMC), both of which were established at the nearby Industrial Technology Research Institute. Other Companies include Acer, D-Link, Giga, Logitech, MediaTek, Microtek, MStar Semiconductor, Nuvoton, Philips, Powerchip Semiconductor, Realtek, Tecom, TSMC and United Microelectronics Corporation. The *Malaysian* Semiconductor cluster hosts a variety of large semiconductor manufacturing sites as well.

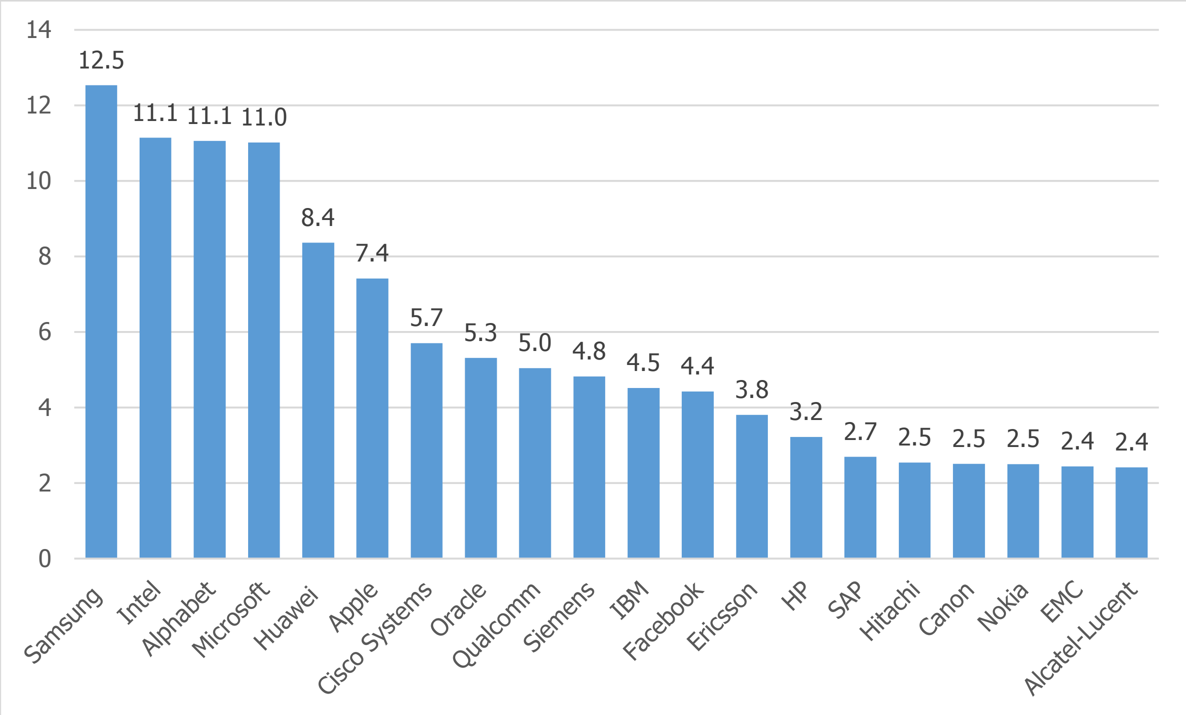
"*Silicon Wadi*", in the coastal plain of Israel, has a high concentration of high-tech industries. The region is particularly strong in Cyber Security and Agritech. The Silicon Wadi area covers much of the country, although especially high concentrations of hi-tech industry can be found in the area around Tel Aviv.

3.5.4. Analysis of R&D activities on the company level based on the EU R&D scoreboard

The overall R&D expenditures of ICT amounted to about €243 billion in 2015/ 2016. This is about 7.8 percent of the overall sales of the ICT that reached more than €3.1 trillion in 2015/ 2016.

The figure below shows that Samsung Electronics Co., Ltd. had the highest R&D expenditures with over €12 billion per annum. Samsung Electronics is one of the leading manufacturer of television, mobile phones, television, semiconductors, OLEDs and other. At R&D intensity at Samsung Electronics is relatively low with 8 percent (see Figure 4), the sales amount to €157 billion, and the second largest sales of all ICT manufacturers worldwide. The headquarters of Samsung Electronics is found at Suwon, South Korea. The second position in the industry is held by Intel Corporation and Alphabet Inc. with R&D expenditures of €11.1 billion. Intel is a technology company headquartered in Santa Clara, California, USA. The company supplies processors for computer system manufacturers and also manufactures motherboard chipsets, network interface controllers and integrated circuits, flash memory, graphics chips, embedded processors and other devices related to communications and computing. The R&D intensity of Intel is relatively high with 21.9 percent and total sales of €51 billion. Alphabet Inc. is parent company for a number of smaller companies, including technology company Google and its former subsidiaries. The R&D intensity of Alphabet is 16 percent and total sales of €69 billion. The headquarters is located in Mountain View, California, USA. Microsoft Corporation is found at the third position with R&D expenditures of €11 billion. The R&D intensity is relatively low with only 14 percent. Sales amount to roughly €78 billion. The company is organized in three divisions: Windows and devices, Cloud and Enterprise and Office Product. Microsoft is headquartered in Redmond, Washington, USA. Microsoft is followed at distance by the Chinese company Huawei (€8.4 billion) and the American companies Apple (€7.4 billion, Cisco Systems (€5.7 billion), Oracle (€5.3 billion) and Qualcomm (€5 billion). Therefore, the most important ICT companies regarding R&D expenditures are located in the United States. Further important locations are South Korea, Japan and China as well as some European countries such as Germany, Sweden and Finland.

Figure 9: R&D expenditures of ICT companies, in € billion, top 20 companies in 2015/2016



Source: VDI TZ, based on the 2016 EU R&D Scoreboard

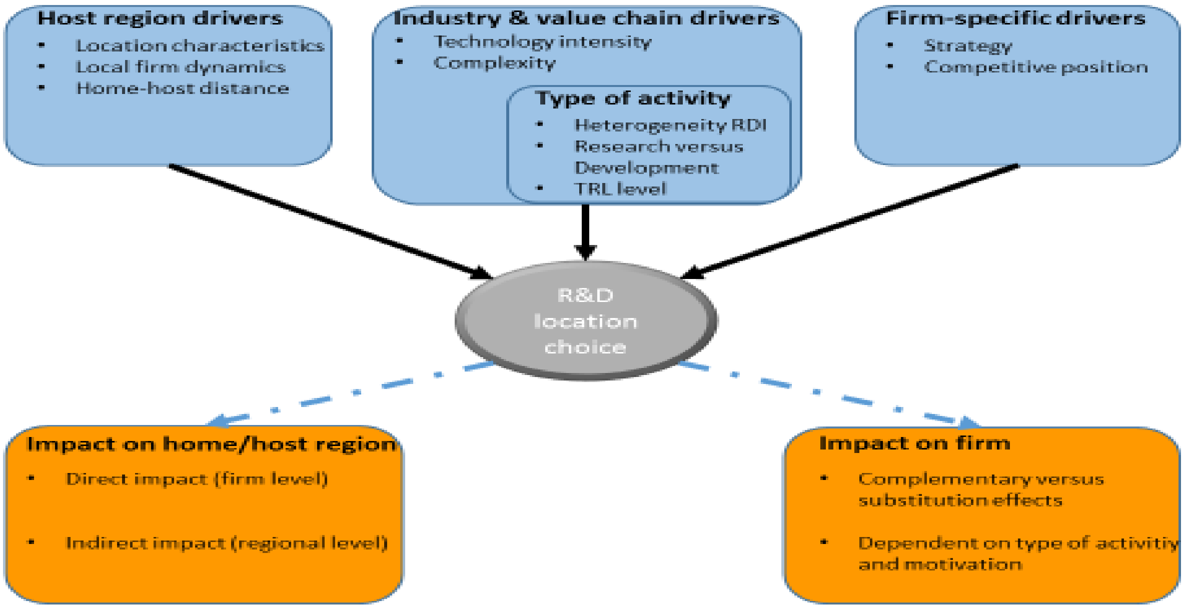
4. Locational drivers for international R&D&I activities, governance modes, interactions and impact on home and host region

4.1. Literature review: Analytical framework on drivers and impact of location decisions

To assess the locational drivers we have relied on the analytical framework that we developed for the first deliverable. This framework is presented in Figure 10 and consists of the various building blocks that have proven to be important to examine and understand R&D&I location decisions.

The analytical framework shows that the R&D&I location decision is driven by 3 main drivers: the host region characteristics, industry and value chain considerations, and firm-specific drivers.

Figure 10: Refined analytical framework



Source: IDEA Consult

4.1.1. Locational drivers

Host region drivers include the location characteristics, local dynamics and home-host region distances. Location characteristics that are important in explaining the location choice can be summarized in market-related factors like demand, human capital and other knowledge-related aspects such as technological strength, but also local infrastructure, cost-related factors like wages or taxes as well as the political and environmental aspects (e.g. IPR regime). These factors may relate to local competition, industrial concentration and international connectivity. Geographic, cultural between home and host country may also play a role.

Industry-related and value chain drivers can also play an important role. These relate to the role of the investing firm's industry and global value chain configuration. The firm's locational decisions may be driven by its international value chain configuration and the configuration of competitors and partners (e.g. internal co-location).

Firm-specific drivers may depend on the firm's strategy and competitive position. Depending on weather a firm is a leader in its market or a follower can determine the location of R&D&I.

The propositions we address related to the **locational drivers** are indicated in the box below. These propositions also relate to **offshoring and outsourcing trends**, the **governance modes** and the role of the **government**.

Box 1: Research questions and propositions that relate to the locational drivers

RQ: How do companies organise their R&D&I acctivities across GVCs?

The analytical framework illustrates the key factors in determining the firm's R&D&I location decision: the host region characteristics, industry and value chain considerations and firm-specific drivers. Traditionally, production activities are highly dispersed across countries, while R&D&I activities only recently started to internationalize. Furthermore, production facilities are strongly driven towards countries with large market demand and low factor costs, while the location drivers of R&D&I activities are more diverse. Within the location decision process of R&D&I activities there is a strong interplay between host country characteristics, and industry-specific and value chain considerations, with the latter factors becoming increasingly important. There is a large heterogeneity within R&D&I activities, with activities at different stages of the R&D&I process subject to different locational drivers. Corporate strategies, however remain decisive in determining the location choices.

Proposition 1) Industry-specific and value chain characteristics are key drivers for R&D&I location decisions and are becoming more important than country characteristics.

Proposition 2) Location determinants and patterns are highly dependent on the type of R&D&I activity (TRL).

Proposition 3) Corporate strategies are decisive in determining the location choices.

RQ: What is the relationship between R&D&I locational decisions and the location of production activities?

The (scarce) literature on the importance of colocation effects between different activities within companies' GVCs seem to suggest that prior production activities in a host location increases the probability that later R&D&I activities follow in the same host region (e.g. Alcácer and Delgado, 2016; Defever, 2012; Alcácer, 2006). Benefits can be derived from collocating these activities as important feedback effects exist between both types of value chain activities (e.g. Defever, 2006; Buciuni and Finotto, 2016). The need for colocation however strongly depends on the type of activity. Ketokivi and Ali-Yrkkö (2009) for instance documented that this need strongly correlates with the knowledge intensity of activities. More specifically, an increasing product and process complexity and a high industry rate of change promotors colocation.

Proposition 4) The extent to which R&D&I activities are collocated with production activities, strongly depends on the type of R&D&I activity involved.

RQ: Which industrial differences can be observed?

Industry differences are observed as the value chains and R&D&I activities vary between industries.

Proposition 5) The organization of R&D&I activities across GVCs is industry/sector specific. Industry differences are observed at the level of the location decision, the impact, the governance mode applied. Even within industry, differences can occur depending on the R&D&I activities (TRL scale) of the company.

Further industrial differences will be specified when the international fragmentation of corporate R&D&I is analysed at the sector level (pharma, ICT production/hardware, automotive/aerospace).

RQ: How functions/activities are sliced (or not) across different subsidiaries, external partners and different territories?

The international fragmentation of R&D&I activities is highly dependent on the complexity, knowledge-intensity and global trends within the industry. Accordingly, outsourcing and offshoring trends will differ significantly across industries.

Proposition 6) Outsourcing and offshoring trends are highly industry-specific. The international fragmentation of R&D&I activities is highly dependent on the industry and R&D&I subfunctions/activities or tasks. Highly capital-intensive industries concentrate key R&D activities to a larger extent than less capital-intensive industries.

RQ: Which corporate governance mechanisms and modes sustain corporate R&D and innovation across GVCs? (alliances, subcontracting, collaborative contracts, IP licensing, subsidiaries chain, …)

With the increasing internationalization of R&D&I activities (i.e. more complex activities), there is a trend towards more advanced corporate governance mechanisms to sustain these international corporate R&D networks. More traditional corporate governance modes have become obsolete and a trend towards global R&D&I networks has been observed. However, a firm's overall strategy and experience with corporate governance mechanisms will largely determine the governance mode and mechanism chosen.

Proposition 7) There are a broad range of corporate governance mechanisms and modes to sustain corporate R&D&I across GVCs. We expect this governance mechanisms/modes to be highly dependent on the type of R&D&I activity/task performed. A trend towards global R&D&I networks (originating due to alliances, collaboration and/ or subcontracting) can be observed, although they are often difficult to manage. The corporate strategy will however be determinant for the decision on the governance mechanism.

RQ: Which policy challenges can be derived?

As indicated in the conceptual framework, there are a broad range of drivers which can influence the location decision of a company: host (home) region, industry & value chain (including type of activity) and firm-specific drivers. The government can provide incentives to attract/sustain R&D investments by improving its infrastructure and legal and political environment and decreasing costs faced by incoming firms (e.g. corporate tax). Providing an attractive environment for R&D&I activities will foster a favourable environment for other activities as well (production, R&D, design, etc) and will lead to an attractive innovation ecosystem. The local dynamics of the competitive environment will be highly relevant for inward R&D investors, especially for firms aiming to source foreign knowledge and collaborate with incumbents.

Proposition 10) The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment.

Proposition 11) The competitive environment of the host region can significantly alter a region’s attractiveness.

Proposition 12) Knowledge spillovers and technology transfers are mainly driven by the governance mode, TRL level and government stimuli.

4.1.2. Impact of location decisions on home and host country and interactions

An overview of the opportunities, challenges and risks associated with the internationalisation of business investment in R&D for both the home and host country is provided in Table 15.

Table 15: Impact of R&D&I Internationalization on home and host countries

	Opportunities	Challenges & Risks
Host country	• Increases in aggregate R&D and innovation expenditure • Knowledge and information diffusion to the host economy (e.g. firms, universities and research centers) • Enhancing the level and quality of human resources as well as increasing demand and job creation for skilled personnel • Structural change, agglomeration effects, contribution to the development of clusters and move towards higher technology intensity • Internationalisation of and complementarity with local R&D activities (i.e. R&D adaptation to low value-added R&D activities of the host country)	• Downgrading of local R&D • Loss of control over domestic innovation capacity and commercialisation • Less strategic research, less radical innovations, more adapting • Separation of R&D and production; leaking out effect of production to third countries • Competition with domestically owned firms for resources (‘Crowding out’)

Home Country	• Improved overall R&D efficiency • Reverse technology transfer and productivity growth of firms' home operations • Positive spillover effects to suppliers and partners (through labor mobility, imitation and linkages) • Market expansion effects and reallocation of market shares • Virtuous cycle between foreign Development, Design and Testing operations and home R&D activities (measured in patent growth). • Exploitation of foreign knowledge at home • Shift towards a non-routine and interactive tasks and increasing demand for highly skilled workforce	• Loss of jobs due to relocation and a downward pressure on wages • 'Hollowing out' of domestic R&D and innovation activities • Technology leakage and involuntary knowledge diffusion

Source: Adapted from Sheehan (2004), UNCTAD (2005), Veugelers (2005), Dachs et al. (2012), Becker et al. (2013), D'Agostino et al. (2013), Castellani & Pieri (2013), Belderbos et al. (2016)

The research questions and propositions we address on this topic are given in the following box.

Box 2: Research questions and propositions that relate to the impact of foreign R&D&I activities and interactions with the home and host region

RQ: What are the main implications for the locational strategy of EU firms, and for EU innovation/attractiveness policy? Which corporate challenges can be derived?

In the analytical framework two types of impacts of R&D&I internationalisation are identified: at the country level and at the firm level. The internationalization of R&D&I entails both opportunities and risks, but the literature mainly stresses the positive aspects. Opportunities for home and host region are mainly related to increases in productivity and innovation performance. These opportunities are highly dependent on the embeddedness of the investing firm and the technological gap between domestic and foreign firms.

> Proposition 8) The impact of the offshoring of R&D&I activities on the home or host country mainly occurs via increased productivity and innovation performance. This is however highly dependent on a set of contingences related to the firm's embeddness and technological capabilities.

The motives for companies to engage in R&D&I internationalisation are aimed to exploit existing technologies (home-base exploiting R&D) or creating new technologies and augmenting the existing knowledge base (home-base augmenting R&D). More recently, the latter motive has become more important. These motivations will also have a different impact on the investing firm. Home-base exploiting R&D will mainly result in increases in sales numbers, while home-base augmenting R&D is closely linked to increases in innovation performance.

> Proposition 9) The home-base augmenting R&D argument is increasingly important in

the location decision of companies. Home-base augmenting R&D will have a stronger impact on the innovation performance than home-base exploiting R&D.

RQ: Which policy challenges can be derived?

innovation as a challenge for national innovation system from internationalisation of R&D&I. This hollowing out effect is however not supported by recent empirical evidence.

Proposition 13) The common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded.

4.2. Cross-sector analysis based on case studies and interviews

Within the project, we have made a cross-sector analysis (for the different sectors of analysis: pharmaceuticals, automotive, aerospace and the ICT) and we have used all propositions formulated above to discuss parallels and differences across the analysed sectors.

These findings are based on: an extensive literature review, the findings and conclusions distilled from the 10 case studies and interviews with industry representatives (for each of the case studies, we conducted around 6 interviews, so a total of around 60 interviews with business representatives, company managers and industry experts have been undertaken in the study). Here below, we discuss all propositions separately and discuss to what extent they are valid across the different sectors. This has also been summarized in Table 16.

In the annex we also discuss these propositions for each sector individually.

Proposition 1: Industry-specific and value chain characteristics are key drivers for R&D&I location decisions and are becoming more important than country characteristics.

This proposition is not valid across all sectors. For the pharmaceutical industry it is shown that value chain considerations only play a limited role in determining the location decision and host country characteristics (e.g. market demand and technological capabilities) are still more decisive in explaining the firm's location behaviour. Value chain considerations are also becoming more important given that companies are increasingly breaking up their value chain (as discussed in 3.1) and are engaging more and more in alliances and collaborations with companies located down – or upstream. Furthermore, for activities at the later TRL scales (TRL7-8) it has become highly beneficial to co-locate R&D&I activities with production activities given that these stages require an extensive upscaling process of the clinical trials. Especially for phase 3 trials (TRL8, which equals 25-30% of the total R&D budget for a typical pharmaceutical firm) it can be important to have a close connection to the manufacturing facility. This makes that value chain considerations are gaining ground in the pharmaceutical sector.

In the aerospace sector, value chain characteristics do not play an important role in explaining the location decision, which is due to the fact that the sector is characterized by strong consolidated supply chains.
In the automotive sector, value chain considerations play a determining role. Companies

active in that sector have a strong desire (especially the OEMs) to locate R&D facilities close to both customers and important suppliers. ICT firms also have a strong desire to be located close to its customers.

Proposition 2: Location determinants and patterns are highly dependent on the type of R&D&I activity (TRL).

Across all case studies it has been shown that location determinants and patterns are highly dependent on the type of R&D&I activity. We have documented that R&D&I activities at the end of the TRL scale (more applied innovative activities, TRL6-9) are driven towards regions with large market demand (mostly in South-East Asia), while the activities at the start of the TRL scale (mainly TRL2-5) are driven towards regions with advanced technological capabilities and a highly-skilled labour force (e.g. USA and Germany). The offshoring of activities at the end of the TRL scale will especially have strong consequences for the pharmaceutical industry as the TRL scales 6-9 constitute of 60-75% of the R&D budget. Within the sector, these activities are increasingly flowing to emerging markets because of cost considerations. These countries can be especially important for reducing costs for conducting clinical trials (they account for between 40% and 60% of total drug development), cost reductions can be the highest for operating phase 2 and phase 3 studies.

Across case studies, it has also been shown that non-R&D innovation activities show a slightly different location pattern compared to more traditional R&D activities. The former activities are more driven by the competitive position in the industry, value chain considerations and local dynamics. Non-R&D innovation activities are especially important in the automotive industry (they account for 13-55% of the total R&D&I budget).

Proposition 3: Corporate strategies are decisive in determining the location choices.

Across all case studies, it has been shown that corporate strategies are very decisive in determining the location choice of companies. It has for instance been shown that location choices are often driven by strategic takeover decisions and the location behaviour is often driven by specialisation strategies (this is mainly the case for the pharmaceutical sector).

Proposition 4: The extent to which R&D&I activities are collocated with production activities, strongly depends on the type of R&D&I activity involved.

In general, weaker co-location forces can be observed in science based industries. The case studies however also show that the extent to which R&D&I activities are collocated with production activities strongly depends on the type of R&D&I activity. In the pharmaceutical sector it can be said that co-location of R&D&I with production is not necessary, but for R&D&I activities situated at the later stages of the TRL scale this co-location becomes more important (TRL6 and later). The same holds for the aerospace sector where higher TRL activities are often collocated with manufacturing facilities or assembly lines. In the ICT sector, it are also mainly the activities at the end of the TRL scale that are co-located with production activities.

In the automotive sector there is a long history of co-locating innovative activities with production activities. Within the sector, it are however mainly the non-R&D innovation activities that are most often co-located (these activities accounts for 13-55% of the total R&D&I budget, which is substantial, in the pharmaceutical sector and the aerospace sector this is for instance only 10%). Especially design activities to improve or adapt existing products and processes is often co-located (this activity accounts for 5-30% of the total R&D&I budget).

Proposition 5: The organization of R&D&I activities across GVCs is industry/sector specific. Industry differences are observed at the level of the location decision, the impact, the governance mode applied. Even within industry, differences can occur depending on the R&D&I activities (TRL scale) of the company.

This proposition can also be confirmed. The most R&D intensive industries of our study are clearly driven towards regions with strong technological capabilities and strategic assets. Less R&D intensive industries (i.e. the automotive industry, which is considered as medium-tech industry) are more driven towards regions with large market demand and favourable factor costs (especially labour costs). Within industries we can also observe large differences depending on the type of R&D&I activity: also as shown by examples in the text above.

Proposition 6 Outsourcing and offshoring trends are highly industry-specific. The international fragmentation of R&D&I activities is highly dependent on the industry and R&D&I subfunctions/activities or tasks. Highly capital-intensive industries concentrate key R&D&I activities to a larger extent than less capital-intensive industries.

The extensive research on this topic has shown that the international fragmentation of R&D&I activities is highly dependent on the knowledge-intensity, the complexity, and global trends within the industry. As such, it has been argued outsourcing and offshoring trends will differ significantly across industries. This has been confirmed by the case studies as well. The most capital-intensive industries in this study, namely the pharmaceutical sector and the aerospace sector report a lower degree of offshoring and relocations compared to other industries (given that relocation costs also could be high). Within these industries offshoring is not that widespread. There is however a clear trends across sectors of more outsourcing and offshoring of activities. Especially activities at the later TRL stages are offshored. Within the pharmaceutical industry, activities at the later stages of the TRL (starting from the later clinical trials, TRL6-7) are increasingly outsourced (via CRO's), while the ICT sector and the automotive sector (OEMs) increasingly rely on their suppliers for their innovation process. Within this latter sector, suppliers typically account for around 50% of R&D spending and typically engineer around 75% of newly developed vehicles. Within the aerospace sector, outsourcing is less common, this can partly be explained by the strategic character of the industry.

Proposition 7: There are a broad range of corporate governance mechanisms and modes to sustain corporate R&D&I across GVCs. We expect these governance mechanisms/modes to be highly dependent on the type of R&D&I activity/task performed. A trend towards global R&D&I networks (originating due to alliances, collaboration and/ or subcontracting) can be observed, although they are often difficult to manage. The corporate strategy will however be determinant for the decision on the governance mechanism

All case studies show there is a trend towards more external governance modes and collaborative R&D networks are being formed (this is however less the case for the aerospace sector where strategic considerations sometimes block more open forms of partnerships). Across sector, there is a trend towards working more in open innovation network where firms engage in strategic alliances with key partner firms. Patent cooperation and patent pools with competitors and suppliers are also becoming more common. The type of partnership of alliance is however dependent on the type of R&D&I activities. Collaborative networks are for instance more formed for activities at the lower levels of the TRL scale (basic research) and often with academic partners and biotech companies. Joint ventures are more popular for production activities and innovative activities at the end of the TRL scale.

Proposition 8: The impact of the offshoring of R&D&I activities on the home or host country mainly occurs via increased productivity and innovation performance. This is however highly dependent on a set of contingences related to the firm's embeddness and technological capabilities.

All case studies conducted in the 4 sectors confirmed this proposition and claimed that international R&D&I operations not only increased the overall innovation performance of the firm but did also contribute to the innovativeness of the region. Across all sector, the extent of this impact is highly contingent on the network of the firm in the host market and the openness of the local foreign ecosystem. Overall firm innovation performance is also increased when companies try to maintain close links between activities in the home and host region and try to stimulate regular exchanges about best practices, new developments, process improvements and new ideas that will lead to cross-fertilization of ideas coming from different regions. Intellectual property rights can also strongly influence the amount of mutual knowledge spillovers between firms. This factor especially plays a role in patent-intensive industries such as the pharmaceutical industry. Pharmaceutical companies are more inclined to implement measures to safeguard their knowledge and are less likely to transfer strategic knowledge to the foreign affiliate and are more likely to limit its responsibilities and independency when the host region is characterized by weak intellectual property rights.

Proposition 9: The home-base augmenting R&D argument is increasingly important in the location decision of companies. Home-base augmenting R&D will have a stronger impact on the innovation performance than home-base exploiting R&D.

Several studies have shown that across industries, home-base augmenting R&D motives (to create new technologies and augment the existing knowledge base) have become more important than home-base exploiting R&D motives (to exploit existing technologies). Furthermore, it has been contended that home-base augmenting R&D activities will lead to the highest increases in innovation performance.
Across all case studies it has been contended that home-base augmenting R&D activities will have the strongest impact on the firm's overall innovation performance as these international activities are more instrumental for generating new ideas and concepts (especially activities situated at the TRL stages 1-4). However, the argument that home-base augmenting R&D motives are becoming more important is only partially confirmed by our case studies. It is only in the aerospace sector that the evidence shows that this motive is gaining important ground. In the other sectors a clear shift of R&D&I activities towards Asia has been documented. This shift is mainly driven by cheap factor costs and market demand (R&D&I activities mainly involve activities to adapt existing products or processes to the market). As such, these activities can be characterized mainly as home base exploiting R&D activities. It is however important to remark here that the technological capacities of Asian regions are increasing substantially such that more recently firms also internationalize their R&D&I activities in Asia to explore and augment their existing knowledge base (home base augmenting R&D activities).

Proposition 10: The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment.

All case studies across all sectors show that the government can play an important role in attracting/sustaining R&D&I investments. The EU can for instance improve its attractiveness for the pharmaceutical industry by focusing on cost-related aspect and the legal and political environment (remark however the cost-related aspect are not the most decisive factor in explaining the location behaviour of pharmaceutical companies). For pharmaceutical companies, favourable tax conditions, strong intellectual property rights, flexible labour laws, funding opportunities, cluster stimuli, less stringent regulation, and labour costs are among the factors that could increase the attractiveness of a region.

For automotive firms, the EU could increase its attractiveness the most by focusing on its infrastructure. Infrastructure in this sense refers to several dimensions: mobility infrastructure (fast roads, railways, efficient airports and efficient public transportation systems), skill and labour market infrastructure (availability of graduates and professionals, good education system), technological infrastructure (charging infrastructure for electric vehicles, technical standards).

Within the aerospace sector, the government can play a decisive role by promoting basic research (TRL1-TRL6), offering better financing options and by better coordinating the access to and the development of available infrastructure.
For the ICT sector, the EU can mainly improve its attractiveness by focusing on lowering the labour costs for highly skilled IT personnel.

Proposition 11: The competitive environment of the host region can significantly alter a region's attractiveness.

The recent literature documented that the competitive environment of the host region can significantly alter a region's attractiveness. Researchers have for instance documented that technology leading firms tend to avoid highly agglomerated areas or cluster for new investments because they fear that outgoing knowledge spillovers might endanger their own competitive position, while other studies have documented that firms tend to stay away from regions characterized by regions where incumbent technology leaders are actively taking measures to avoid outgoing knowledge spillovers.
This proposition is only partly confirmed by all case studies. In the pharmaceutical industry, the competitive environment of the host region in the pharmaceutical industry is for instance not a decisive factor in explaining a firm's location behaviour. Most established pharmaceutical companies currently are evolving towards a more open innovation culture and even try to establish collaboration agreements and alliances with their closest competitors. In the automotive sector, this environment also only has modest influence and the sector is characterized by a trend that firms are moving towards the most competitive environment because they need to learn from other firms (also in other sectors) in order to remain competitive and stay on track.

In the aerospace sector, most firms have a very consolidated supply chain (because of high economic and technological barriers) and they develop their own ecosystems and do not take the locations of other competing firms into account. In the ICT sector the competitive environment does play a role, but not to the extent that larger firms shed away from the most agglomerated places.

Proposition 12: Knowledge spillovers and technology transfers are mainly driven by the governance mode, TRL level and government stimuli.

This proposition is confirmed by our case study of the aerospace industry but it is only partially valid for the three other sectors (pharmaceuticals/automotive/ICT). Across the case studies there is however a consensus that the governance mode and the TRL level have a strong influence on the amount of knowledge spillovers. The amount of knowledge spillovers will be the highest for strong equity-based governance models (i.e.

subsidiaries and acquisitions) but they are also stimulated intensively within alliance and collaborations. Furthermore, it has been argued that knowledge spillovers will be the highest at lower TRL levels. For the aerospace sector it has been argued that government stimuli are also important drivers for knowledge spillovers and technology transfers. The government can for instance stimulate knowledge spillovers through the implementation and support of collaborative projects such as Clean Sky or Sesar.

Proposition 13: The common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded.

The fear that foreign R&D&I operations might lead to a possible 'hollowing out effect' of domestic R&D and innovation is often expressed by popular press, even though recent empirical evidence does not support this hollowing out effect. All companies involved in the different case studies did not report job losses or negative relocation effects on the activities in the home region, it is argued that foreign R&D&I activities are more complementary with the operations in the home region. As such the proposition is valid for all sectors. This proposition is especially valid for the pharmaceutical industry. This industry reduces redunancy and maximizes complementarity by organizing its R&D&I centres in such a way that each location has a specific expertise and focus (topic wise). Foreign R&D&I activities are also granted a high independency and are organized in such a way that they feed in and complement the ideas of the main R&D&I hub in the home country.

Table 16: Cross-sector analysis

Propositions	Pharmaceutical sector	Mobility		ICT-manufacturing
		Automotive sector	Aerospace sector	
1) Industry-specific and value chain characteristics are key drivers for R&D&I location decisions and are becoming more important than country characteristics.	+/-	+	-	+
2) Location determinants and patterns are highly dependent on the type of R&D&I activity (TRL).	++	+	+	+
3) Corporate strategies are decisive in determining the location choices.	+	+	+	+
4) The extent to which R&D&I activities are collocated with production activities, strongly depends on the type of R&D&I activity involved.	+/-	+	+	++
5) The organization of R&D&I activities across GVCs is industry/sector specific. Industry differences are observed at the level of the location decision, the impact,	+			

the governance mode applied. Even within industry, differences can occur depending on the R&D&I activities (TRL scale) of the company.				
6) Outsourcing and offshoring trends are highly industry-specific. The international fragmentation of R&D&I activities is highly dependent on the industry and R&D&I subfunctions/activities or tasks. Highly capital-intensive industries concentrate key R&D&I activities to a larger extent than less capital-intensive industries.	+			
7) There are a broad range of corporate governance mechanisms and modes to sustain corporate R&D&I across GVCs. We expect these governance mechanisms/modes to be highly dependent on the type of R&D&I activity/task performed. A trend towards global R&D&I networks (originating due to alliances, collaboration and/ or subcontracting) can be observed, although they are often difficult to manage. The corporate strategy will however be determinant for the decision on the governance mechanism.	+	+	+/-	+
8) The impact of the offshoring of R&D&I activities on the home or host country mainly occurs via increased productivity and innovation performance. This is however highly dependent on a set of contingences related to the firm's embeddedness and technological capabilities.	+	+	+	+
9) The home-base augmenting R&D argument is increasingly important in the location decision of companies. Home-base augmenting R&D will have a stronger impact on the innovation performance than home-base exploiting R&D.	+/-	+/-	-	+/-
10) The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment.	+	+	+	+

11) The competitive environment of the host region can significantly alter a region's attractiveness.	**-**	**+/-**	**-**	**+/-**
12) Knowledge spillovers and technology transfers are mainly driven by the governance mode, TRL level and government stimuli.	**+/-**	**+/-**	**+**	**+/-**
13) The common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded.	**++**	**+**	**+**	**+**

5. Attractiveness of sites in Europe from a company perspective

The tables below list the factors that determine the attractiveness of Europe for companies based in the different sectors of the analysis. Each of these tables is constructed based on a cross-case analysis of all case studies and interviews with key experts active in the industry (with the purpose to better generalize the findings for the broader industry).

Table 17: Factors determining the attractiveness of Europe, for companies based in the pharmaceutical sector

Factors increasing attractiveness of sites in Europe
• well-established, reliable intellectual property laws • direct effects foreign policies in Asia and the United States affecting trade and investment aimed at limiting free trade / protectionism, making sites at foreign regions less attractive • The companies interviewed are historically situated in Europe and have strong existing networks and knowledge clusters in this region as well as a detailed knowledge of legal and economic frameworks • historically there were very capital-intensive investments to establish the current sites in Europe, relocation costs to other world regions in many cases would be very high • Europe, especially Germany, France and the UK are the largest and most important markets for the selected companies • Academic excellence is an important aspect for the companies as graduates from strong universities are a relevant aspect of successful innovation activities in the future • Excellent conditions and infrastructure • High quality parts and pieces of automotive products of European producers • Good transport infrastructure • Many companies of the supply chain built up competencies in other world regions (e.g. Asia). They learn a lot about the foreign markets and technologies like electromobility, which in turn generates benefits for the locations in Europe (due to increased knowledge) • Cluster initiatives and public support initiatives (e.g. funding, investment grants)
Factors decreasing attractiveness of sites in Europe
• The companies follows their customers. This makes locations out of Europe more attractive as sales in Asia, especially China, have increased much more than sales in Europe during recent years , thus more and more customers are located in these regions • Some Asian countries and the US are specialized in specific technological fields, while Europe/ Germany are only specialized in automotive sector • A weakness is seen in poor charging infrastructure for electric vehicles in large parts of Europe. When electromobility will spread, this is a serious risk for the European market as is could develop slower than other regions. A big problem is the poor density of charge stations for electric vehicles in many regions. The lack of standards for charging technology in Europe increases this weakness. • A weakness of Germany is strong perfectionism during the development of new products as it may prevent continuous progress. It is a strength in relation to completed products. • relatively high labour costs decrease attractiveness of Europe in relation to other world regions, especially Asia

Table 18: Factors determining the attractiveness of Europe, for companies based in the automotive sector

Factors increasing attractiveness of sites in Europe
• well-established, reliable intellectual property laws • direct effects foreign policies in Asia and the United States affecting trade and investment aimed at limiting free trade / protectionism, making sites at foreign regions less attractive • The companies interviewed are historically situated in Europe and have strong existing networks and knowledge clusters in this region as well as a detailed knowledge of legal and economic frameworks • historically there were very capital-intensive investments to establish the current sites in Europe, relocation costs to other world regions in many cases would be very high • Europe, especially Germany, France and the UK are the largest and most important markets for the selected companies • Academic excellence is an important aspect for the companies as graduates from strong universities are a relevant aspect of successful innovation activities in the future • Excellent conditions and infrastructure • High quality parts and pieces of automotive products of European producers • Good transport infrastructure • Many companies of the supply chain built up competencies in other world regions (e.g. Asia). They learn a lot about the foreign markets and technologies like electromobility, which in turn generates benefits for the locations in Europe (due to increased knowledge) • Cluster initiatives and public support initiatives (e.g. funding, investment grants)
Factors decreasing attractiveness of sites in Europe
• The companies follows their customers. This makes locations out of Europe more attractive as sales in Asia, especially China, have increased much more than sales in Europe during recent years , thus more and more customers are located in these regions • Some Asian countries and the US are specialized in specific technological fields, while Europe/ Germany are only specialized in automotive sector • A weakness is seen in poor charging infrastructure for electric vehicles in large parts of Europe. When electromobility will spread, this is a serious risk for the European market as is could develop slower than other regions. A big problem is the poor density of charge stations for electric vehicles in many regions. The lack of standards for charging technology in Europe increases this weakness. • A weakness of Germany is strong perfectionism during the development of new products as it may prevent continuous progress. It is a strength in relation to completed products. • relatively high labour costs decrease attractiveness of Europe in relation to other world regions, especially Asia

Table 19: Factors determining the attractiveness of Europe, for companies based in the aerospace sector

Factors increasing attractiveness of sites in Europe
• Well developed and connected ecosystem: access to supply chain and other large companies • Presence of manufacturing sites • Highly skilled labour force • Presence of industry clusters (with good networking opportunities) • Access to EU collaborative initiatives (SESAR, CleanSky, etc) • The presence of complementary organisations: research and technology organisations • Academic excellence • High production standard • Access to clients • Gaining critical mass • Quality of life • Transport
Factors decreasing attractiveness of sites in Europe
• Lack of support for lower TRL research: more investments in TRL 1 TO 6 would be needed • Capacity to maintain and attract talent, which is increasingly driven by working in projects and mission and not by stable working conditions • Difficult – burdensome - access to public sector support • Costly infrastructure and lack of coordination between the technology capabilities existing in Europe and the financial support offered by the public sector • Labour market regulations • Soaring labour costs

Table 20: Factors determining the attractiveness of Europe, for companies based in the ICT sector

Factors increasing attractiveness of sites in Europe
• well-established, reliable intellectual property laws • well-established, reliable privacy policy • political and economic stability • direct effects foreign policies in Asia and America affecting trade and investment aimed at limiting free trade / protectionism, making sites at foreign regions less attractive • Companies historically situated in Europe tend to have strong existing networks and knowledge clusters in these regions as well as a detailed knowledge of legal and economic frameworks • In the semiconductor industry historically there were very capital-intensive investments to establish the current sites in Europe, relocation costs to other world regions in many cases would be very high • Emergence of industry 4.0 combined with a high productivity of European labour force has reduced the negative impact of relatively high European wages in recent years • Initiatives like IPCEI now give additional support • Some countries in Central and Eastern Europe are fast growing markets • Europe provides availability of skilled employees, which is an important locational driver • Europe, especially Germany, France and England, are important ICT regions
Factors decreasing attractiveness of sites in Europe

• Companies often prefer fast growing markets since there are still fewer rules and laws of business than in mature economies. In these markets, there is more scope for action and a greater chance to establish as market leader. Except of the Central and Eastern Europe countries, European markets are mature
• The ICT-industry is highly capital-intensive, however, relocation costs are not high
• Favourable tax systems in some world regions may make locations there more attractive
• Availability of skilled employees is an important locational driver. In recent years the number of skilled engineers and university graduates in countries like China and India has increased significantly. Higher wages in Europe are a very important cost factor of locational decisions
• strong competition regulation within the European Union has decreased attractiveness in recent years
• In some industries like semiconductors the most important locational driver is "proximity to application". These companies often follow their customers. This makes locations out of Europe more attractive as
    ○ sales in Asia (and America) have increased much more than sales in Europe during recent years , thus more and more customers are located in these regions
    ○ protective measures and policies affecting trade and investment in foreign regions may prevent customers from opening new sites in Europe
    ○ initiatives like the "Made in China 2025" program may lock some customers to regions outside of Europe
• higher energy / electricity costs in combination with a high degree of regulation decrease attractiveness of sites in European countries in some cases

6. Policy toolbox for the upgrade of the EU industry in GVCs

The European Commission stresses in a Communication of 2017 "a new industrial age" with economic, societal and environmental transformations and technological breakthroughs (e.g. robotics, Internet of Things, artificial intelligence). These changes go along with automation, digitized manufacturing processes and the nature of work. Furthermore, industry is more and more integrated in global value chains with important service components. In this Communication it is suggested that the Member States, EU institutions and industry itself need important efforts "to maintain and reinforce Europe`s industrial leadership." This means that it is for instance necessary to fill the missing links in relevant value chains. One important step is to facilitate the integration of European companies in global value chains in R&D and innovation which are the essential drivers of industrial competitiveness. Besides this, missing links in value chains have to be filled with investment in a strategic way as demonstrated in the field of new batteries for smart mobility. In this Communication it is also stressed that there has to be a focus on "strategic value chains" in new technology which has to be well coordinated and financed by public authorities and industries from several Member States. In another recent Communication on "Strengthening Innovation in Europe's Regions" the European Commission (2017b) stresses the beneficial link between innovation and smart specialisation in the regions. The Smart Specialisation Strategy (S3) has the aim to encourage Europe's regions to identify their specific competitive advantages to better prioritise public research and innovation. Another import step is therefore to organise new forms of co-operation on an inter-sectoral level and across regions. This means global value chains in R&D and innovation are an important additional element of S3 in Europe.

Upgrading industry in the EU by using policy instruments needs concrete instruments and mixed instruments. Otherwise there is the risk that the current industrial renaissance is just a flash in the pan. The following policy tool box shows special instruments and combinations of policy instruments e.g. for the appropriate development of human resources, efficient research and innovation infrastructures and absorptive capacities and the identification of needs of companies R&D and innovation linked with their existing and new GVCs. Besides this, the outline based on the case studies on companies of the studied sectors (pharmaceutical, automotive, aerospace and ICT) and interviews done for this study provide options on how public authorities on different levels can tackle new challenges for innovation and industry by organizing collaborative opportunities for innovation und industrial actors.

When the instruments of the policy tool box to upgrade GVC in R&D and innovation in Europe is described in the following figures a distinction between short term and medium/long term instruments and options is suggested. The following figure shows a number of instruments which fall into three categories (regulatory, economic and financial, soft). Option 1 combines 3 short term instruments which are of low costs. Option 1 is of low cost since for activities like matchmaking events and studies just very limited resources are needed. Option 2 (see next figure) combines 5 short term instruments which are of medium costs. Option 2 is of medium cost because EU actions, programmes and initiatives discussed here usually have a medium time horizon. Depending on the resources available Option 1 and 2 could be combined.

Figure 11: Policy instruments for an ambitious short term policy: Option 1

Instrument	Regulatory	Economic and financial	Soft
Support of systemic forward looking vision in GVC R&D and innovation, e.g. by studies, events for learning			
Identify key value chains in R&D and innovation in new areas, e.g. by studies, interviews and expert discussion			
Supporting of matchmaking events on different levels			

Source: VDI Technologiezentrum

Figure 12: Policy instruments for an ambitious short term policy: Option 2

Instrument	Regulatory	Exonomic and financial	Soft
Strengthening and expanding cooperation between major innovation, research and industrial actors in fields of specialization and inter/cross-sectoral innovation			
Improving cross-border value chains in Europe (and possibly with developing countries by using virtual ways of cooperation)			
Supporting Platforms and hubs for new thematic partnerships in breakthrough thematic areas like industrial robotics, smart mobility or smart data			
Synergy of investment between private and public sector on different levels (International, European, national, regional, local)			
Strengthening a proactive attitude among policy makers towards a proactive innovation policy			

Source: VDI Technologiezentrum

The next figure shows a number of medium/long term instruments which also fall into three categories. Option 3 combines 3 instruments which are of medium costs. Option 3 is of medium cost because EU actions, programmes and initiatives discussed here usually have a medium time horizon. They are in general more costly than the ones in Option 2 since more resources are needed for instance for the infrastructure in education, training and new technology.

Option 4 (see the next figure) combines 4 instruments which are of high costs. Option 4 is of high cost since the instruments discussed here are long term. The actions etc. could not be stopped short term. Also the experimental character would be much more limited compared to the other options. Depending on the resources available Option 1 and 2 could be combined to reach positive results with low/medium resources operating on an experimental base like innovation labs. Option 1 and 2 could be short-term or medium-term stopped while the loss of resources would be quite limited. In addition to this, a combination of all 4 options might be possible if quite some resources are available. But if all these instruments fail the loss of resources would be very high. The advantage of options 1 and 2 is that – being used in an experimental way – they costs would be relatively low if the instruments do not provide the results expected. If options 3 and 4 do not provide the results expected the costs are very high. A less costly but pragmatic mix of short term and medium/long term instruments would be combining Option 2 and 3.

Figure 13: Policy instruments for an ambitious short term policy: Option 3

Instrument	Regulatory	Economic and financial	Soft
Organize impetus events for new innovation networks in breakthrough areas			
Bridging between excellent research and specific training and education programmes at universities, vocational schools and primary and secondary education system			
Investment in educational infrastructure and new technologies (e.g. universities)			

Source: VDI Technologiezentrum

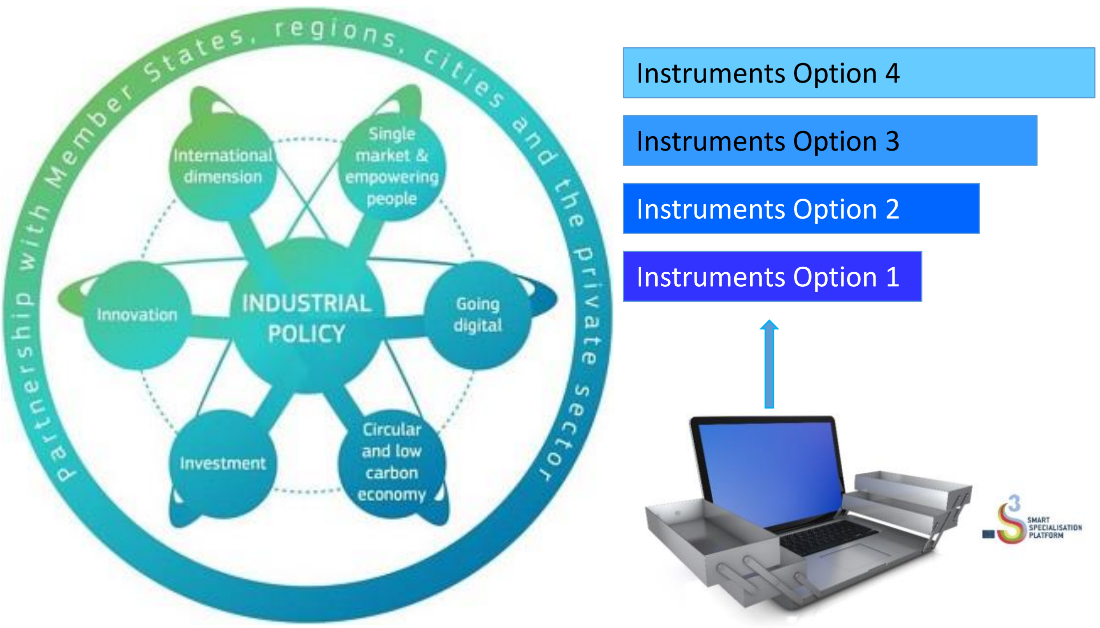
Figure 14: Policy instruments for an ambitious short term policy: Option 4

Instrument	Regulatory	Economic and financial	Soft
Capital investment well-co-ordinated and linked with the societal grand challenges (e.g. EIB and EFSI) and creating and shaping new markets)			
Supporting R&D and innovation on the ground			
Supporting Leadership in key innovations			
Creation of an innovation culture linked with sophisticated integration (migrant workers)			

Source: VDI Technologiezentrum

As described in the Communication by the European Commission for a renewed industrial policy strategy efforts on the European level have to be matched by national and regional reform efforts. There is a need to join forces behind a holistic and comprehensive strategy for industrial competitiveness linked with the policy tool box and the options of policy instruments discussed above (see next figure). Quite a number of these instruments are already used in a systematic mix on the national/regional level.

Figure 15: New forms of industrial policy linked with a policy toolbox (short/medium/long term)



Source: VDI Technologiezentrum based on European Commission (2017) and photo by Fotalia / Thomas Jansa

Following this approach gives numerous "established" and new actors from business, politics, science and society from different Member States, regions and cities but also actors from outside the EU the chance to develop bright ideas for new products, services, processes and work in a well-structured but also open-minded and inter-sectoral environment. This can/should be done across regions and in an inter-sectoral way. Like in the innovation labs of companies an experimental character is a major factor. Experimental innovation approaches for a new industrial era have to be accompanied by innovation and industrial policies which also create a positive mind-set for R&D and innovation in business and society. Besides this, such an approach helps regions to develop systematically in new fields of innovation and industry which are appropriate for the region and their actors thinking beyond traditional limits and borders.

Strengthening a proactive attitude among policy makers towards a proactive innovation policy is a soft but important instrument to speed up for a new industrial age in Europe and it is not very costly. Besides this, it important to stress that the Industry 4.0 innovation and industrial policy initiative stands already for an outstanding example for the use of combing different policy instruments and options successfully (e.g. creating new products, processes and services based on the EU's industrial strength). The importance to transfer research results into the education system not only at the academic level but especially for non-academics has increased considerably. There is a real need for good vocational training to have regional skillsets of production workers who now need IT skills and process knowledge (Malanowski/Krug 2017). Such an approach or similar ones could also be used for finding new combinations of trends at large level (e.g. tourism and renewables) and integrate them via a process involving all stakeholders at the regional level, especially companies and also citizens and knowledge creators. In this respect, also from the policy side thinking out of the box is highly important. This includes the combination of flexible instruments for experimentation in a new era of EU innovation and industrial policy that has shifted from the orthodox top-down approach to a bottom-up approach. This would connect very well to the trends of fragmented innovation processes across the companies' GVCs and regions.

7. Conclusion

This project was undertaken to have a better understanding of the geographical and organizational patterns of corporate R&D and Innovation (R&D&I) activities across Global Value Chains (GVCs) and their interactions with home and host-countries' economies and policy initiatives. Furthermore, the project was conducted to better understand the obstacles and drivers of knowledge-intensive activities in Europe and how we can improve the competitive position of EU industry in strategic GVCs.

This project has these topics and has looked at international R&D&I activities within global value chains of companies based in the pharmaceutical sector, the automotive sector, the aerospace sector, and the ICT sector. For each of these sectors, an extensive literature review has been performed and the study has worked with 10 case studies and numerous interviews to collect detailed information on recent location patterns, trends and challenges. For all sectors it has been examined how companies organise their R&D&I activities across GVCs. More specifically, the study has examined the functional distribution of R&D&I activities and Technological Readiness Levels (TRLs) were chosen to conceptualise these activities at the company level. Within these activities, the study has also looked at the distinction between R&D and non-R&D innovation activities and how they might be subject to different locational drivers and organizational mechanisms. For companies based in the selected sectors of this study, the study has analysed their locational strategy of R&D&I activities and how these activities have an impact on the home and host region. Furthermore, the project has looked at corporate governance modes to undertake these innovative activities and the differences across sectors. As part of the analysis, the attractiveness of the European Union has also been assessed for R&D&I activities within these sectors and derived policy challenges and recommendation on how the EU can improve its attractiveness. All these topics were examined with the help of an analytical framework and carefully developed propositions with respect to drivers and impact of location decisions. These propositions were tested for each case study and the broader sector. In addition, a cross-case analysis has been conducted to test to what extent these propositions can be validated across sectors

The project has documented that R&D&I activities are still increasingly internationally dispersed. Yet, R&D&I activities are very heterogeneous and many different types of innovative activities exist. R&D&I activities for instance exist of R&D and non-R&D innovation activities which can be both very important in the innovation process. The latter activities however only receive limited attention in the broader literature. In this study it is shown that the most important non-R&D innovation activities are: (i) design to improve and adapt existing products and processes and (ii) the acquisition of machinery and equipment. This study has also contended that the importance of non-R&D innovation activities is rising more recently, although the important of these activities differs significantly across sectors. Non-R&D innovation activities are especially important in the automotive industry where they account for around 13-55% of the total R&D&I budget. Throughout the study it however became clear that it remains difficult to find suitable indicators to monitor these activities by multinationals: they are not always monitored internally by the firms, are difficult to grasp and are often included in the traditional R&D activities.

It is also shown that industry-specific and value chain characteristics are important drivers for R&D&I location decisions but are not more important than country characteristics. It is however contended that value chain considerations are becoming more important given that companies are increasingly breaking up their value chain and are engaging more and more in alliances and collaborations with companies located down – or upstream. Furthermore, the study has shown that locational determinants and patterns are highly dependent on the type of R&D&I activity: e.g. innovative activities at the end of the TRL scale (more applied innovative activities, TRL6-9) are driven towards regions with large market demand (mostly in South-East Asia), while the activities at the start of the TRL scale (mainly TRL2-5) are driven towards regions with advanced technological capabilities and a highly-skilled labour force. On top of that, the study shows that across sectors, non-R&D innovation activities show a slightly different location pattern compared to more traditional R&D activities.

The study also shows that corporate strategies are decisive in determining the firm's location choice: location choices are for instance often driven by strategic takeover decisions and specialisation strategies. Based on the case studies, it is shown that the governance mode to undertake international R&D&I activities is also driven by the corporate strategy. There is however a clear trend towards collaborative R&D networks and a trend towards working more in open innovation network where firms engage in strategic alliances with key partner firms. Patent cooperation and patent pools with competitors and suppliers are also becoming more common. This governance mode is however also dependent on the type of R&D&I activities: joint ventures are for instance more often used for innovative activities closer to the commercialisation phase, while alliances are more often formed for technological research or even fundamental research.

The study also documents that R&D&I activities are still often collocated with production activities: often, though it largely depends on to what extent the industry is science-based and one the type of R&D&I activity; innovative activities closer to commercialisation (situated at the higher TRL's) are more often collocated with manufacturing facilities or assembly lines. The study has also shown that non-R&D innovation activities such as design activities are often collocated.

Another important finding is that locational patterns are highly industry-specific: most knowledge-intensive industries of our study are clearly driven towards regions with strong technological capabilities and strategic assets, while less knowledge-intensive industries are more driven towards regions with large market demand and favourable factor costs. Highly capital-intensive industries concentrate key R&D&I activities to a larger extent than less capital-intensive industries.

When looking at the impact of international R&D&I activities, it can be confirmed that these activities increase not only the overall innovation performance of the firm but did also contribute to the innovativeness of the region. In the project it is however argued and confirm by multiple interviewees that the he extent of this impact is highly contingent on the network of the firm in the host market and the openness of the local foreign ecosystem. Overall firm innovation performance is also increased when companies try to maintain close links between activities in the home and host region and try to stimulate regular exchanges about best practices, new developments, process improvements and new ideas that will lead to cross-fertilization of ideas coming from different regions. The impact also strong depends on the type of R&D&I and it is contended that home-base augmenting R&D activities have a stronger impact on the innovation performance than home-base exploiting R&D as these international activities are more instrumental for generating new ideas and concepts (especially activities situated at the TRL stages 1-4).

Another important conclusion of the project is that knowledge spillovers and technology transfers are mainly driven by the governance mode, type of R&D&I activity (TRL level) and government stimulus; the amount of knowledge spillovers will for instance be the highest for strong equity-based governance models (i.e. subsidiaries and acquisitions) and activities at lower TRL levels (more basic-oriented research). The government can also stimulate knowledge spillovers through the implementation and support of collaborative projects (e.g. Clean Sky and Sesar in the aerospace sector).

Another important finding of the study is that the common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded. This is mainly because firms in knowledge-intensive industries try to reduce redundancy in international operations and maximize complementarity by organizing its R&D&I centres in such a way that each location has a specific expertise and focus. Furthermore, foreign R&D&I activities are increasingly granted a high independency and are organized in such a way that they feed in and complement the ideas of the main R&D&I hub in the home country. On top of that, most-strategic knowledge is mostly still kept at the headquarters in the home region.

When looking at the factors that determine the attractiveness of the European Union, the study has evidently highlighted differences across sectors in the project, but several common factors were observed (for the sectors within this study).

According to interviewees (industry representatives, company managers and industry experts) factors that increase the attractiveness of Europe are among others:

- *Reliable IP laws*
- *Political and economic stability*
- *Strong existing networks and markets*
- *Skilled labour force*
- *Academic excellence*
- *Growing excellence in industry 4.0 and high production standards (ICT, mobility)*
- *Growing markets in Eastern Europe*
- *Protectionism abroad*
- *EU collaborative / cluster initiatives*
- *Developed infrastructure (e.g. transportation, infrastructure to conduct clinical trials)*
- *Tax conditions to stimulate R&D*

Factors that are decreasing Europe's attractiveness include among others:

- *Skilled employees combined with low wages (mainly in Asia: India, China …)*
- *Favourable tax systems abroad*
- *Restrictive labour market (e.g. pharmaceutical regulations in Europe)*
- *Lack of investments in new infrastructure (e.g. for electromobility)*
- *Proximity to customers abroad is becoming increasingly important*
- *Protectionism preventing customers moving to Europe*
- *Good but very costly infrastructure, energy costs*
- *Little support for high TRL investments (e.g. in aerospace and pharma)*
- *No central R&D organizations that are steering research in the sector (e.g. in pharma)*

These factors already show that government can play an instrumental role in increasing Europe's attractiveness. This was clearly confirmed within this study as well. The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment. Within the study, some interviewees have also claimed that more government funding should flow to R&D&I activities at the later TRL stages. Currently, by far the most R&D&I funding goes to R&D&I activities at the lower TRL phases although the large majority of the corporate R&D&I budget flows to activities at the later TRL phases. Especially in capital-intensive industries the share of these activities is very high (e.g. in the pharmaceutical sector innovative activities situated at TRL6-8 account for 45-55% of the total R&D&I budget). Large multinationals have limited problems with financing these stages, but smaller firms currently face many difficulties with finding financing for these activities (especially since R&D subsidies typically focus on the financing of R&D personnel, while activities at the later TRL phases typically consist more of capital expenditures, e.g. for demonstration infrastructure, pilot lines, validation and certification tests) and as a consequence often fail to reach the final commercialisation phase. Additionally, it was also argued that non-R&D innovation activities are more difficult to finance than traditional R&D innovative activities.

Within the study a policy toolbox has been developed to move beyond the current European, national, regional and sectoral policy instruments and which provided mixes of policies based on the insights obtained throughout the study.
As part of the policy toolbox it has been argued that there exist three categories of policy instruments that are most accepted in the literature on innovation policy instruments: a) regulatory instruments (IPRs, university statutes), b) economic and financial instruments (tax exemptions, competitive research funding, …) and c) soft instruments (voluntary standardisation, codes of conduct, public-private partnerships). The case studies and interviews with company representatives collected for this study show a high interest in these new policy instruments to improve the attractiveness of Europe for innovative activities. A strong interest was especially expressed in the last two categories. It was also shown that company representatives prefer proactive instruments for bridging the gap between high-level research and a suitable education plus an

adequate infrastructure thus strengthening the training of highly skilled young academics at universities and skilled workers at vocational schools for instance in the areas of ICT, Big Data, Robotics, Life Sciences and New Materials to upgrade Global Value Chains in R&D&I in Europe. It was also argued that for innovations with a highly experimental character (e.g. innovations labs), a highly flexible innovation and industrial policy is necessary. A number of interviewees have also made the point that there is a worldwide trend towards more multidisciplinary/multi-sector collaborations. These interviewees stress that the EU should stimulate and support these projects more since they are essential for the further industrial modernisation of European industry. From the interviewees' point of view it was also argued the Smart Specialisation Strategy – if followed more strictly – could be a good strategy to reduce the enormous duplication of research efforts within the EU and could align research efforts better across borders.

This study has shed more light on the international fragmentation of R&D&I activities within global value chains of multinational companies, but at the same time also points to avenues of further research. Within the study has for instance shown that innovation labs of companies with a highly experimental character are becoming more and more a major factor in R&D and innovation, yet little research is done on these type of activities and accordingly, more qualitative and quantitative research on this recent development is needed.

Another field with a lack of solid information is the role of cultural diversity for innovation and innovation and industrial policy. Recent research studies on diversity and innovation show mixed results on this question. Some of the studies come to the general conclusion that diversity has a positive influence on innovation (e.g. Mir-Babayev 2017; Ozgen et al. 2013). Other recent studies point out that the ethnic background might play an important role and that an improved innovation level can be empirically observed when well educated ethnic groups from Asia participate in innovation activities (Gompers/Wang 2017; Brixy et al.). These first results show already that there does not seem to be a fast answer to this question. Very interesting is that the companies which were interviewed for this study pointed out that quite often there is a quite high degree of cultural diversity for instance their teams working in innovation labs with a highly experimental character.

Besides this, more information is needed on how to transfer excellent research into the education system not only at the academic level but especially for non-academics has increased considerably.

Recent research on innovation and industrial policy stresses the need of an intelligent governance of policy instruments and measures. Scholars like Edler/Fagerberg (2017) make the case for four governance principles. These are anticipation, participation, deliberation and transparency. From there point of view these principles are necessary to ensure that societal preferences and concerns are taken into account in R&D and innovation processes and policies. Kuhlmann/Ordonez-Matamoros (2017) argue that in addition it is necessary to discuss failures of innovation governance from the past to better understand opportunities of today. One very important governance problem in the field of innovation and industrial policy is that there is still a lack of concern of the international dimension of R&D and innovation. These policies are quite often still organized on the national and/or regional level and not like for instance newly establishes innovation labs of companies on an international level. To get around this problem it is necessary to get more information on how linking the international dimension GVCs with strategies already existing.

Annex

Box 3: Propositions for the pharmaceutical sector

Proposition 1) Industry-specific and value chain characteristics are key drivers for R&D&I location decisions and are becoming more important than country characteristics.

In the broader literature review we argued that within the location decision process of R&D&I activities there is a strong interplay between host country characteristics, and industry-specific and value chain considerations, with the latter factors becoming increasingly important.

It could be argued that given that this industry is highly-R&D intensive it mainly locates its foreign R&D&I activities in locations with high technological capabilities and in regions known for the presence of well-developed industry clusters. The desk research results for the pharmaceutical industry showed that the value chain considerations are not top priority when contemplating where to locate a new R&D&I facility. For instance, R&D activities within the pharmaceutical industry can be more easily separated from production activities (compared to other industries) and traditionally pharmaceutical companies cover a large part of the innovation value chain (although this latter aspect is changing more recently and firms are increasingly outsourcing parts of their R&D pipeline). In Europe we can observe that pharmaceutical companies concentrate their R&D&I and production activities in a few regions and that both activities are often located in close vicinity. However, we see that this pattern is historically driven (the breaking up of the value chain in the pharmaceutical industry is a more recent phenomenon) and not driven by considerations to benefit from co-location.

In the case studies, it was confirmed that value chain considerations only play a limited role in determining the location decision of pharmaceutical companies. It is argued that host country characteristics such as the market demand, the technological capabilities and the opportunities to network with other partners in the country/region are still more decisive in explaining the firm's location behaviour.

Nevertheless, it becomes clear that value chain considerations are becoming more important and this for several reasons. One of the reasons is the emergence of large developing markets where many inventive products and instruments are based on cost innovation processes, and for this innovation process co-location of production and R&D&I activities is more necessary. Companies that would like to benefit from the rise of these large markets should consequently co-locate their R&D&I activities more with production activities in these markets. Furthermore, for activities located at the later TRL stages, it can highly beneficial to co-locate R&D&I activities with production activities given that these stages require an extensive upscaling process of the clinical trials. Especially for phase 3 trials (TRL8) it can be important to have a close connection to the manufacturing facility. Given that this phase takes a large chunk of the total R&D&I budget, companies are starting to realize that it is important to co-locate these activities in this phase of the innovation process. Value chain considerations are also becoming more important given that companies are increasingly breaking up their value chain and are engaging more and more in alliances and collaborations with companies located down – or upstream. As such, it is becoming more important to be located close to for instance suppliers or biotech companies that could perform part of the needed basic research.

Proposition 2) Location determinants and patterns are highly dependent on the type of R&D&I activity (TRL).

In the desk research, we have already documented that the location drivers for outward R&D activities in the pharmaceutical industries are largely dependent on the type of R&D offshored (i.e. the TRL). Non-clinical studies for example (TRL 1- TRL 4) generally occur in the more advanced regions which have the technology for undertaking these studies and which typically also have a tradition of partnerships between research institutions such as universities. Accordingly, these early stage research activities are mainly located in advanced regions such as Northern America, the European Union and Japan. Late preclinical research (TRL 5) and Phase 1 trials (TRL 6) also often entail greater technological challenges than the following stages, so currently they are also predominantly located in the triad countries. Recent studies however show that emerging markets (and not only in Asia) are getting increasingly important as locations for clinical trials (the later TRL stages). That is partly because cost considerations are also becoming very important in the location decision process as clinical trials can account for between 40% and 60% of total drug development and merging countries can be very important to reduce operational costs. Cost reductions can be the highest for operating phase 2 and phase 3 studies in emerging market regions as on average, they account for more than 40% of total R&D investments. The internationalization of clinical trials to these regions can also shorten the duration as they often have a great potential for study participants, which can significantly accelerate the recruitment process. We have also documented that since cost reductions are highest for Phase 2 and Phase 3 clinical trials, most of the trials undertaken in emerging countries can be found in of these 2 types of R&D activities. It was also indicated in interviews that clinical trials starting from phase 2 (TRL 7) are increasingly internationalized to non-developed markets as the market demand from these countries (especially in Asia) is getting more and more important and that medicines and vaccines need to adjusted to different genes (across continents)?

In the case studies we have confirmed that location determinants and patterns are indeed highly dependent on the type of R&D&I activity. These case studies for instance show a shift of activities at the later stages of the TRL to Asian regions, but not mainly because of cost considerations, but also to access these large markets. It is argued that R&D&I activities at the end of the TRL scale (more applied innovative activities) are driven towards regions with large market demand (e.g. China), while the activities at the beginning of the TRL scale are driven towards regions with advanced technological capabilities and a highly-skilled labour force (e.g. USA and Germany). It is also indicated that for more strategic R&D&I activities (e.g. fundamental research, preclinical research), strategic considerations also become more important. One of the surveyed companies for instance indicated that they want to maintain the most strategic activities close to its HQ in order to better safeguard and nurture this knowledge.

Proposition 3) Corporate strategies are decisive in determining the location choices.

Corporate strategies haven been proven to be very decisive in determining the location choice of pharmaceutical companies. This propositions has been confirmed clearly by all case studies. One of the companies for instance argued that the decision to enter the Chinese market was largely driven by strategic considerations (to set up R&D antenna/scouting agency). Another company indicated that most of its foreign R&D&I

locations were driven by recent strategic takeover decisions, while another company pointed out that its foreign R&D&I location pattern is mainly driven by a clear specialisation (in terms of research expertise and topics) strategy.

Proposition 4) The extent to which R&D&I activities are collocated with production activities, strongly depends on the type of R&D&I activity involved.

The broader literature showed that benefits can be derived from collocating R&D&I activities with production activities as important feedback effects exist between both types of value chain activities. It has also been show that that prior production activities in a host location increases the probability that later R&D&I activities follow in the same host region. Nevertheless, weak co-location forces can be observed in science based industries, such as the pharmaceutical industry, where firms' R&D&I laboratories can have a strong focus on scientific discovery and basic research. The extent to which R&D&I activities are collocated with production activities could however strongly depend on the type of R&D&I activity involved.

This is clearly confirmed by all the case studies. In general, it is argued that co-location of R&D&I with production is not necessary, but for R&D&I activities situated at the later stages of the TRL scale this co-location becomes more important. One of the surveyed companies also indicated that R&D&I activities in the field of competitive manufacturing and in the field of the implementing new manufacturing technologies and processes take place right at their production sites.

Proposition 5: The organization of R&D&I activities across GVCs is industry/sector specific. Industry differences are observed at the level of the location decision, the impact, the governance mode applied. Even within industry, differences can occur depending on the R&D&I activities (TRL scale) of the company.

- ➔ See cross-sector analysis

Proposition 6) Outsourcing and offshoring trends are highly industry-specific. The international fragmentation of R&D&I activities is highly dependent on the industry and R&D&I subfunctions/activities or tasks. Highly capital-intensive industries concentrate key R&D&I activities to a larger extent than less capital-intensive industries.

Literature shows that the international fragmentation of R&D&I activities is highly dependent on the complexity, knowledge-intensity and global trends within the industry. Consequently, outsourcing and offshoring trends will differ significantly across industries.

The pharmaceutical industry is an industry with a very particular outsourcing and offshoring behaviour. Until the late 1990s, most companies performed almost everything in-house and offshoring was very rare. This has however changed dramatically and nowadays these companies are increasingly breaking up their value chains and outsourcing and collaboration agreements occur more and more at all segments of the innovation value chain. Nevertheless, given that the pharmaceutical industry is a highly capital-intense industry offshoring and relocation processes are not that widespread as in other industries (given that relocation costs also could be high). For the companies involved in the case studies we have also documented that the large majority of their R&D&I activities is still being conducted at the HQ.

Proposition 7) There is a broad range of corporate governance mechanisms and modes to sustain corporate R&D&I across GVCs. We expect these governance mechanisms/modes to be highly dependent on the type of R&D&I activity/task performed. A trend towards global R&D&I networks (originating due to alliances, collaboration and/ or subcontracting) can be observed, although they are often difficult to manage. The corporate strategy will however be determinant for the decision on the governance mechanism.

In the pharmaceutical industry a broad range of governance modes is being used to manage international R&D&I activities: Subsidiaries, Subcontracting, Collaborations, Strategic partnerships, etc. Although, the R&D&I operations of one of the case study companies are still very internally driven (subsidiaries), all companies clearly indicate there is trend towards more external governance modes. More specifically, there is a clear trend towards collaborative R&D networks. These networks are especially formed for activities at the lower levels of the TRL scale (basic research) and often with academic partners and biotech companies. However it is very important to remark that the type of network and collaboration is very dependent on the partner. With other competing pharmaceutical companies collaborations will for instance focus more on complementary activities/topics while collaborations with academic partners (not considered as competitors) can also focus on non-complementary and or strategic activities/topics. Joint ventures are more popular in the area of production activities.

Based on our case studies we can also state there is an interest towards more collaborations with partners active in complementary industries but with technologies and applications that could also be useful in the pharmaceutical industry (e.g. robotics, microelectronics, …)

Proposition 8) The impact of the offshoring of R&D&I activities on the home or host country mainly occurs via increased productivity and innovation performance. This is however highly dependent on a set of contingences related to the firm's embeddedness and technological capabilities.

In the literature, most studies stress the positive aspects and opportunities that foreign R&D&I activities have for both the home and host region (mainly related to increases in productivity and innovation performance). It is however argued that this is highly dependent on a set of contingences related to the firm's embeddedness and technological capabilities.

The case studies confirmed this picture and stress that the international R&D&I operations clearly increased the overall innovation performance of the firm and contributed to the innovativeness of the region. The companies involved in the case studies claimed that the extent of the impact that a foreign R&D&I affiliate has is highly dependent on its network in the foreign market and the openness of the local ecosystem.

Companies also try to maintain close links between activities in the home and host region and try to stimulate regular exchanges about best practices, new developments, process improvements and new ideas that will lead to cross-fertilization of ideas coming from different region, which will eventually lead to an increased overall innovation performance. As such the impact that a foreign R&D&I affiliate has on the home and host region, and the firm itself depends on the embeddedness of foreign affiliate in the host region, on the embeddedness of the parent company in its home region, but also on the embeddedness of the foreign subsidiary in the parent company.

It is also stressed that the interaction that the foreign affiliate has with other firms in the host region and the amount of mutual knowledge spillovers with local firms is highly dependent on the intellectual property rights regime in the host regime. If the host region is characterized by a weak IPR regime, pharmaceutical companies are more inclined to implement measures to safeguard their knowledge and are less likely to transfer strategic knowledge to the foreign affiliate and are more likely to limit its responsibilities and independency.

Proposition 9) The home-base augmenting R&D argument is increasingly important in the location decision of companies. Home-base augmenting R&D will have a stronger impact on the innovation performance than home-base exploiting R&D.

Literature indicates that the motives for companies to engage in R&D&I internationalisation are either aimed to exploit existing technologies (home-base exploiting R&D) or creating new technologies and augmenting the existing knowledge base (home-base augmenting R&D). Furthermore, it has shown that across industries, this latter motive has become more important and has also been argued that home-base augmenting R&D will lead to the highest increases in innovation performance.

Results from the case study analysis indicates that for the pharmaceutical industry, home-base augmenting motives are also gaining ground (although one of the interviewed companies claimed that these motives are in balance). Additionally, it is confirmed that home-base augmenting R&D activities will have the strongest impact on the firm's overall innovation performance as these international activities are instrumental for generating new ideas and concepts (more than home-base exploiting R&D activities).

Proposition 10) The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment.

The results indicated in **Error! Reference source not found.** Table 17 which summarizes the factors that determine the attractiveness of Europe for pharmaceutical companies immediately makes clear that the government can play a substantial role in attracting R&D&I investments. Favourable tax conditions, strong intellectual property rights, flexible labour laws, funding opportunities, cluster stimuli, less stringent regulation, and labour costs are among the factors that could increase the attractiveness of the region. These are all factors that could be heavily influenced by government policy measures. The results of the case studies however showed that the infrastructure and the cost-related aspects are not factors that are decisive in explaining the location behaviour of all pharmaceutical companies.

Proposition 11) The competitive environment of the host region can significantly alter a region's attractiveness.

Some recent studies showed that the competitive environment of the host region can significantly alter a region's attractiveness. It has for instance been shown that technology leading firms tend to avoid highly agglomerated areas or cluster for new investments because they fear that outgoing knowledge spillovers might endanger their own competitive position. Other studies have documented that firms tend to stay away from regions characterized by regions where incumbent technology leaders are actively taking measures to avoid outgoing knowledge spillovers.

In our case studies (where we focus on leading pharmaceutical companies), we actually find that the competitive environment of the host region in the pharmaceutical industry is not a decisive factor in explaining a firm's location decision. It is highlighted that most established pharmaceutical companies currently are evolving towards a more open innovation culture and even try to establish collaboration agreements and alliances with their closest competitors.

Proposition 12) Knowledge spillovers and technology transfers are mainly driven by the governance mode, TRL level and government stimuli.

This proposition is only partially confirmed by our case studies.

Pharmaceutical companies for instance indicate that the amount of spillovers will evidently be the highest among internal branches of the company (subsidiaries) and are also stimulated the most within alliances and collaborations. One of the interviewed companies also regularly organises training and education programmes to stimulate regular knowledge spillovers and technology transfers. It is also argued that companies especially try to seek for knowledge spillovers within collaborations at the lower levels of the TRL scale (i.e. more basis research).

Companies indicate that government stimuli are only partially relevant for stimulating knowledge spillovers. Governments can however indirectly stimulate knowledge spillovers between companies by setting up funding programmes that stimulate the formation of consortia consisting of different (types of) organisations working on a specific project. Establishing Public-Private-Partnerships (PPP) can also be highly relevant.

Proposition 13) The common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded.

Some studies indicate that foreign R&D&I operations might lead to a possible 'hollowing out effect' of domestic R&D and innovation, which will of course pose a challenge for the national innovation system of the home country. This is also often feared by popular press, even though recent empirical evidence does not support this hollowing out effect.

The case study analysis confirm this proposition and claim this fear is unfounded. The companies involved in our case studies did not report any job losses or negative relocation effects on the activities in the home region. It is argued that foreign R&D&I activities of pharmaceutical companies are more complementary with the operations in the home region because they mainly organize their R&D&I centres in such a way that each location has a specific expertise and focus (topic wise). This way, redundancy is also reduced. It is also claimed that foreign R&D&I activities are often given a high independency but are organized in such a way that they should feed in and complement the ideas of the main R&D&I hub in the home region such that the knowledge base and the R&D&I activities of the home regions will further increase.

Box 4: Propositions for the automotive sector

Proposition 1) Industry-specific and value chain characteristics are key drivers for R&D&I location decisions and are becoming more important than country characteristics.

Overall value chain considerations play a determining role for the companies. The presence in technologically advanced countries, which are specialized in specific fields, is highly relevant. Furthermore, the companies desire to locate R&D facilities close to customers in order to better understand their particular market requirements. Thus, it is important for automotive companies not to be located only in Europe and USA, but also in Asia to get a better understanding of Asian customer's needs. These customer groups often demand more sophisticated technical features inside of their cars and often prefer city vehicles, while customers in Germany on average tend to care more about the efficiency of the engine and safety issues. In addition, OEMs will often be strongly co-located with their suppliers.

Generally proximity to customers and markets is an important aspect for the attractiveness of locations. These are often determined by industry-specific characteristics and technology such as electromobility and autonomous driving. Locational decisions are also made in order to learn about new and emerging technologies in the field where those technologies are applied first. If regions lag behind in the application of those technologies, they become less attractive. This goes hand in hand with understanding the demands and needs of customers. Suppliers, on the other hand, often come from all world region. With respect to the acquisition of machinery and equipment geographical proximity is highly relevant.

In the automotive industry many companies have grown by Mergers and Acquisitions in a historical process. If a firm is attractive enough for the business model of another company and acquisition is an attractive option, the location is only one of several relevant aspects. Thus, it can be regarded a key driver of locational decisions.

Country characteristics on the other hand still remain relevant. Important factors driving the attractiveness of countries is the supply of skilled employees on the labor market (e.g. good universities), labor costs, public support and funding programs as well as mobility and technology infrastructure.

Labour costs are a key locational driver within the industry. We can observe a gradual investment shift towards regions with lower operating costs. Attractive regions in that respect are Southern America, Mexico, Eastern Europe and South-East Asia.

Proposition 2) Location determinants and patterns are highly dependent on the type of R&D&I activity (TRL).

R&D locations decisions are mainly driven by strategic considerations, technology intensity of the industry as well as heterogeneity among R&D&I activities.

In contrast, non-R&D innovation activities and production activities are rather driven by the competitive position in the industry, value chain considerations, location characteristics and local dynamics.

There is a desire to locate R&D facilities close to customers in order to better understand their particular market requirements. It ensures that development is closely aligned with the needs of the market, which maximizes the likelihood of financial returns on R&D expenditures. As a consequence, new international R&D investments are expected to take place in the regions displaying the strongest growth numbers, such as South America, India and China. These emerging markets are expected to account for more than 80% of future growth. It is however important to note that new R&D activities in these markets mainly refer to modifications to existing production vehicles to suit local market tastes (i.e. more development oriented activities).

A final important location driver of R&D activities is the availability of technological capabilities and skills. This is especially important for the more research-oriented activities. These activities will be mainly driven towards developed economies. It is important for firms to be present in relevant industry clusters to learn from customers and competitors about new markets and the application of new technologies in these markets.

Proposition 3) Corporate strategies are decisive in determining the location choices.

The corporate strategy is highly relevant for the location choice. As was illustrated above locational choices are often driven by mergers and acquisition decisions and not by country specific characteristics. Depending on the type of business strategy and if it focuses rather on quality or costs the locational decision is influenced by labor costs, availability of skilled personnel and quality standards of the industry cluster.

Proposition 4) The extent to which R&D&I activities are collocated with production activities, strongly depends on the type of R&D&I activity involved.

As discussed above R&D locations decisions are mainly driven by strategic considerations, technology intensity of the industry as well as heterogeneity among R&D&I activities. These are often not co-located with production activities which are rather driven by the competitive position in the industry, value chain considerations, location characteristics and local dynamics. Non-R&D innovation activities are often co-located with production activities.

Proposition 5) The organization of R&D&I activities across GVCs is industry/sector specific. Industry differences are observed at the level of the location decision, the impact, the governance mode applied. Even within industry, differences can occur depending on the R&D&I activities (TRL scale) of the company.

Product characteristics certainly influence the organization of R&D&I activities. For large machinery and equipment it is usually too expensive to ship them over long distances. Small fragile semiconductors within cars usually require a co-location of development and production sites. Other types of pieces and parts come from all world regions and geographic distance is less relevant. As products greater differ among different industries, the organization of R&D&I activities is heterogeneous, too.

- ➔ See also cross-sector analysis

Proposition 6) Outsourcing and offshoring trends are highly industry-specific. The international fragmentation of R&D&I activities is highly dependent on the industry and R&D&I subfunctions/activities or tasks. Highly capital-intensive industries concentrate key R&D&I activities to a larger extent than less capital-intensive industries.

Outsourcing and offshoring trends are industry-specific. A major reason preventing relocation to other countries for many capital-intensive companies are relocation costs. Other reasons are that the knowledge about the home region (from social, juridical and economic aspects) is usually much better than the knowledge about foreign region. Employees with a great amount of firm-specific human capital a personally often strongly linked to their home region. This finding is confirmed by the two case studies.

From the desk research it was shown for the automotive industry that the increasing complexity and the reliance on a growing number of underlying technologies with roots in different industries causes firms more and more outsource their activities. For that purpose, automotive OEM increasingly rely on their suppliers for a large portion of the innovations in new vehicles (e.g. AEA, 2012). These suppliers have become important drivers for innovations and more and more they undertake the initial development of innovative new technologies (with OEMs often providing joint funding). This also makes that suppliers take on more risk. They account for around 50% of R&D spending and typically engineer around 75% of newly developed vehicles. Typically, OEMs currently only undertake the powertrain and body shell engineering entirely in-house. This intense collaboration between automotive OEMs and suppliers is particularly observable in Europe.

As suppliers have taken on a larger role in design and innovation, they have typically established their design centres close to OEMs to facilitate collaboration (Sturgeon et al., 2008). The customary just-in-time and lean management principles also make that the geographical location of the outsourcing partner is highly dependent on the firm's own geographical configuration. However, the increasing reliance on electronics and related industries within the automotive industries, makes that outsourcing more and more flows to regions particularly strong in these areas (e.g. South Korea and Japan).

The offshoring patterns of R&D activities in the automotive industry are mainly explained by 4 locational drivers. Firstly, there is a desire to locate R&D facilities close to customers in order to better understand their particular market requirements. It ensures that development is closely aligned with the needs of the market, which maximizes the likelihood of financial returns on R&D expenditures. As a consequence, new international R&D investments are expected to take place in the regions displaying the strongest growth numbers, such as South America, India and China. These emerging markets are expected to account for more than 80% of future growth. It is however important to note that new R&D activities in these markets mainly refer to modifications to existing production vehicles to suit local market tastes (i.e. more development oriented activities).

Secondly, value chain considerations are extremely important in the automotive industry, and OEMs will be strongly co-located with their suppliers.

Labour costs are a third key locational driver within the industry. We can observe a gradual investment shift towards regions with lower operating costs (Sturgeon et al., 2008). Attractive regions in that respect are Southern America, Mexico, Eastern Europe and South-East Asia.

A final important location driver of R&D activities is the availability of technological capabilities and skills. This is especially important for the more research-oriented activities. These activities will be mainly driven towards developed economies. Research on key components will most likely take place in Europe. This region is currently well-positioned in the automotive sector. It dominates the premium brand sector and this is where new technology and innovation first comes to market. Additionally, Europe has particular strength in the design and development of fuel efficient and high performance internal combustion engines for all market segments. On top of that, Europe is strong in the electronics industry of which applications are increasingly used in the automotive industry. Other regions are however pulling ahead in key areas of electro-mobility such as hybrid technology and battery development (e.g. Japan, Korea, and China more recently). Japan for instance leads the world in the development of hybrid vehicles. It also has a dominant market position in battery and cell manufacturing for electric vehicles. China also boasts a strong electronics and battery manufacturing base and this is coupled with an increasing strength in the important area of telematics.

Proposition 7) There are a broad range of corporate governance mechanisms and modes to sustain corporate R&D&I across GVCs. We expect these governance mechanisms/modes to be highly dependent on the type of R&D&I activity/task performed. A trend towards global R&D&I networks (originating due to alliances, collaboration and/ or subcontracting) can be observed, although they are often difficult to manage. The corporate strategy will however be determinant for the decision on the governance mechanism.

The companies of the cases studies source strategic knowledge through its open innovation network wherein they engage in strategic alliances with key partner firms. Within these alliances, knowledge diffusion is highly stimulated as firms work closely together. Depending on the world region different corporate governance mechanism and modes to sustain corporate R&D&I across GVCs exist. In China Joint Ventures with local Chinese companies are particularly relevant, whereas in most other world regions subsidiaries are more common.

Proposition 8) The impact of the offshoring of R&D&I activities on the home or host country mainly occurs via increased productivity and innovation performance. This is however highly dependent on a set of contingences related to the firm's embeddedness and technological capabilities.

Foreign innovation activities significantly increase the companies' knowledge of the regions. This knowledge refers to all kind of host region drivers like regional economic and geopolitical developments, technological strengths and weaknesses, recruitment of skilled employees in these regions, competitors, knowledge about partners.

This way several companies of the automotive supply chain can built up competencies in other world regions (e.g. Asia). They learn a lot about the foreign markets and technologies like electromobility, autonomous driving, and foreign consumer demands which in turn generates benefits for all locations of the supply chain in Europe (due to increased knowledge)

Overall a Win-win situation can be established, where both the host region and the sites in Europe benefit.

Proposition 9) The home-base augmenting R&D argument is increasingly important in the location decision of companies. Home-base augmenting R&D will have a stronger impact on the innovation performance than home-base exploiting R&D.

Literature indicates that the motives for companies to engage in R&D&I internationalization are either aimed to exploit existing technologies (home-base exploiting R&D) or creating new technologies and augmenting the existing knowledge base (home-base augmenting R&D). Furthermore, it has shown that across industries, this latter motive has become more important and has also been argued that home-base augmenting R&D will lead to the highest increases in innovation performance.

Results from the case study analysis indicate that this proposition holds for the automotive industry. As proximity to customers and markets is relevant and more and more customers are located in Asia, a lot of relevant knowledge for the R&D activities in Germany can be generated by experiences at the sites in foreign countries. Market knowledge, customer knowledge and technology knowledge are all incentives for automotive companies to participate in these markets.

Thus, it can be confirmed that home-base augmenting R&D activities will have the strongest impact on the firm's overall innovation performance as these international activities are instrumental for generating new ideas and concepts (more than home-base exploiting R&D activities).

Proposition 10) The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment.

From the interviewed companies point of view the most relevant policy for governments to attract and sustaining R&D&I investments is infrastructure. Infrastructure in this sense refers to several dimensions:

- mobility infrastructure: Fast roads, railways, efficient airports and efficient public transportation systems)
- skill and labor market infrastructure: Availability of graduates and professionals supported by a powerful education system in the country
- Technological infrastructure: With respect to the automotive industry and the trend towards electromobility, there is an urgent need for a good charging infrastructure for electric vehicles in Europe. In this respect, a high density of charge stations for electric vehicles is required and standards of charging technology need to be determined.
- Legal infrastructure: The legal framework plays a key role for the diffusion of specific new technologies like autonomous driving. E.g. when accidents with autonomous vehicles occur, the liability needs to be clear. At the same time laws should not be too restrictive so that they do not prevent the diffusion of new technology. Also ITC security and ITC laws play an important role as these technology have developed rapidly during the past decades, but the legal framework is adjusted only slowly. On the other hand, the automotive industry innovative activities are hardly driven by the host region's intellectual property laws according to the interviewed companies.

Besides that, political stability and continuity is a relevant aspect for most companies and usually regarded as one of the strength in Europe, although there is a wish to invest more in infrastructure (e.g. charging stations for electronic vehicles).

Proposition 11) The competitive environment of the host region can significantly alter a region's attractiveness.

The competitive environment of the host region has currently a modest influence in the studied cases as the interviewed companies has achieved the position of market leadership in most of its core segments.

On the other hand, new competitors are entering the automotive industry who come from other sectors. In particular electronics, home appliances, and electrical/mechanical machines are quickly entering the market as modern vehicles receive more and more electronic components. Even Google and Apple may turn into car producers in the near future. The competitiveness within the automotive industry is thus significantly increasing. Connected and intelligent cars, autonomous driving and electromobility are main technological trends companies need to adapt.

This can lead to a dichotomy, especially for SME and automotive parts suppliers. Some firms who participated very early in regions with very competitive environments will be prepared for the future. Other SME who avoided competitive markets and focused on traditional segments are at risk to be replaced by firms of other industry if the diffusion of new technologies persists. Hence competitive regions are deterring and attractive for automotive companies at the same time. Strategically companies need to form new alliances to manage these challenges.

Proposition 12) Knowledge spillovers and technology transfers are mainly driven by the governance mode, TRL level and government stimuli.

The TRL level and government stimuli are only partially relevant for knowledge spillovers in the case of automotive industry. The emergence of clusters is highly technology and market driven. Infrastructure and the overall competitive environment of the host regions, however, plays an important role (see above).

Proposition 13) The common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded.

The case study analysis confirm this proposition and claim this fear is unfounded. The companies involved in our case studies did not report any job losses or negative relocation effects on the activities in the home region.

Sites in Asian countries (and other world regions with emerging economies) are usually considered a win-win situation for domestic locations of the European companies as new knowledge and access to new markets can be acquired, which in turn helps domestic sites. The costs to relocate a site are very high and most sites have developed historically though a process of mergers and acquisitions.

From a company point of view the conflict is less between regions, but rather between different industries: In the automotive sector new competitors from other industries (electronics, home appliances, and electrical/mechanical machines) are quickly entering the market as modern vehicles receive more and more electronic components. From a company-perspective this is a much bigger threat to their business than internationalization. Electronic vehicles require fewer components than vehicles with combustion engines. A complete restructuring of the automotive industry and its supply chains could put several traditional firms under severe pressure. Only innovative firms of the automotive parts suppliers will be able to adapt the new technologies quickly enough without being replaced by firm from other industries. To most relevant emerging technologies are electromobility, ICT and autonomous driving.

Box 5: Propositions for the aerospace sector

Proposition 1) Industry-specific and value chain characteristics are key drivers for R&D&I location decisions and are becoming more important than country characteristics.

The literature review showed that in the location decision process of R&D&I activities, the most relevant factors were related to host country characteristics and industry-specific and value chain considerations, being the latter increasingly important.
However, it also showed that the aerospace industry has a rather consolidated supply chain due to its complexity and the high technological and economic barriers it faces. The evidence gathered on this sector clearly indicates that, as a highly-R&D intensive industry, this sector tends to locate its foreign R&D&I activities in locations with high technological capabilities and in regions known for the presence of well-developed industry clusters. This is especially relevant for EU locations. Interviews and desk research have pointed out that the R&D activities carried out outside Europe by EU large aircraft manufacturers of the aerospace sector remain limited in relative terms: most of the R&D activities are still performed in Europe. However, there is an increasing trend for the outsourcing of R&D, especially in low TRLs, to other countries in order to access new technologies, capabilities or skills that are not available in Europe.

Proposition 2) Location determinants and patterns are highly dependent on the type of R&D&I activity (TRL).
The evidence gathered in interviews and desk research highlights that location determinants in the aerospace sector are heavily contingent upon the type of R&D&I activity. Research at lower TRLs is usually carried out though collaboration with universities, research and technology centres or start-ups, it is easier, cheaper and less risky to promote. As such, large EU aircraft manufacturers seem to be prone to develop this type of collaboration with highly specialized centres around the world: the key factor being access to technology or talent.
Projects developed at higher TRLs are more costly and riskier. This type of research tends to be developed in-house, is more likely to be carried out in the same centres as – or close to - manufacturing plants. Collaborations with external partners on this type of research tend to be developed with stable industrial partners (e.g. suppliers or competitors participating in joint ventures or collaborative EU projects, like the Clean Sky initiative).

Proposition 3) Corporate strategies are decisive in determining the location choices.

Corporate strategies are decisive in determining the location "approach": in general in-house R&D is carried out in the home countries. The location of R&D activities is often the result of past mergers and acquisitions which were decided according to the corporate strategy of the time. With respect to collaboration with external partners, all evidence suggests that companies are increasingly adopting open innovation practices although the ways though which this is done varies across companies. Some companies tend to give a large liberty to their engineering units to select the best-in-class partners to collaborate with. Other companies also promote these external collaboration, but do so in a more centralized way.

Proposition 4) The extent to which R&D&I activities are collocated with production activities, strongly depends on the type of R&D&I activity involved.

Previous research has pointed out the benefits that are associated to the collocation of R&D&I activities with production activities. The important feedback effects between both types of activities are evident in the aerospace industry, where higher TRL activities are often collocated with manufacturing facilities or assembly lines. The evidence gathered for this sector also confirms the previous studies that have shown that prior production activities in a host location increases the probability that later R&D&I activities follow in the same host region. Closer-to-market R&D activities are usually located in sites where a manufactruring site is already operating. These activities enable a more cost-efficient way to test and demonstrate technologies in a real environment.

Proposition 5: The organization of R&D&I activities across GVCs is industry/sector specific. Industry differences are observed at the level of the location decision, the impact, the governance mode applied. Even within industry, differences can occur depending on the R&D&I activities (TRL scale) of the company.

- ➔ See cross-sector analysis

Proposition 6) Outsourcing and offshoring trends are highly industry-specific. The international fragmentation of R&D&I activities is highly dependent on the industry and R&D&I subfunctions/activities or tasks. Highly capital-intensive industries concentrate key R&D&I activities to a larger extent than less capital-intensive industries.

Outsourcing and offshoring is less coming in this sector due to its strategic nature.

Proposition 7) There are a broad range of corporate governance mechanisms and modes to sustain corporate R&D&I across GVCs. We expect these governance mechanisms/modes to be highly dependent on the type of R&D&I activity/task performed. A trend towards global R&D&I networks (originating due to alliances, collaboration and/ or subcontracting) can be observed, although they are often difficult to manage. The corporate strategy will however be determinant for the decision on the governance mechanism.

The evidence gathered through interviews and desk research indicates that there is a strong trend towards more external governance modes in the aerospace sector. However, given the specificities of the sector (high economic and technological barriers) in general this greater openness does not entail a reduction of the internal R&D activities, but rather a search for additional capabilities and technologies that are not available in Europe – or that are difficult to develop.

Proposition 8) The impact of the offshoring of R&D&I activities on the home or host country mainly occurs via increased productivity and innovation performance. This is however highly dependent on a set of contingences related to the firm's embeddedness and technological capabilities.

The companies analysed have grown over the years through a process of mergers and *acquisitions and in some cases a significant part of their shares are state-owned. Nonetheless, the case studies analysed show that foreign R&D&I activities have a positive impact on the company´s innovation performance and on the innovativeness of the region*.

Proposition 9) The home-base augmenting R&D argument is increasingly important in the location decision of companies. Home-base augmenting R&D will have a stronger impact on the innovation performance than home-base exploiting R&D.

Previous studies on the field indicate that companies can follow two main strategies when engaging in R&D&I internationalisation: they can aim at exploiting existing technologies (home-base exploiting R&D) or at creating new technologies and augmenting the existing knowledge base (home-base augmenting R&D). The literature indicates that the latter is increasingly common. The evidence gathered in the case studies indicates that the aerospace industry is increasingly driven by home-base augmenting R&D motivations when it comes to setting up collaborations with centres of expertise and research outside Europe. This is seen as having a stronger impact on the innovation performance of the companies by gaining access to new skills and expertise.

Proposition 10) The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment.

Interviews from companies and other types of stakeholders have stressed the increasing competition that the aerospace sector is experiencing from other world regions. In order to address this and maintain competitiveness levels, the interviews have shown some consensus on a series of issues, most notably the need to:

- To promote public sector support for research carried out at TRLs 1 to TRL6.
- To offer better financing options to be able to compete with what other countries in the world are offering
- To better coordinate the access to and the development of infrastructures available in Europe
- To invest in the development of skills, attraction and retention of talent in key technologies for the sector.

Proposition 11) The competitive environment of the host region can significantly alter a region's attractiveness.

Most of the major locations of the aerospace industry in Europe have emerged around the existence of a manufacturing plant of one of the large aircraft manufacturers. These companies tend to be the incumbent technology leaders or, at least, be at the centre of their ecosystem (principals). As such, and due to the high economic and technological barriers, this sector has a rather consolidated supply chain. In this sense, the large manufacturing companies do not tend to locate their facilities in the same locations as their competitors, they already develop their own ecosystems around their manufacturing facilities.

Proposition 12) Knowledge spillovers and technology transfers are mainly driven by the governance mode, TRL level and government stimuli.

The most important drivers for knowledge spillovers and technology transfers according to the cases analysed in this study are related to government stimuli, to the governance mode and, partially related to this, to the TRL. The former are important drivers of knowledge spillovers through the implementation and support of collaborative projects such as Clean Sky or Sesar. Governance modes are important on two different levels: First, through mergers and acquisitions: most of the large companies in the aerospace sector have had in the past a policy of mergers and acquisitions with the aim to acquire new technology and/or manufacturing capabilities. Second, through the establishment of collaboration agreements with research institutes and universities. This type of collaboration mainly focuses on the lower TRLs.

Proposition 13) The common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded.

The empirical evidence analysed for this research indicates that this proposition is confirmed. The trend towards a greater R&D&I internationalisation is not hollowing out domestic innovation in the aerospace sector. The main reasons for this is that R&D&I internationalisation tends to be more visible in research at lower TRLs but the core R&D&I activities for large aerospace companies are found on closer-to-market development stages.

Box 6: Propositions for the ICT sector

Proposition 1) Industry-specific and value chain characteristics are key drivers for R&D&I location decisions and are becoming more important than country characteristics.

Overall value chain considerations play a determining role for the company. Especially the presence near customers is highly relevant for most ICT companies. However, the major driver of locational decisions is to find talented young employees, which are cost efficient. Therefore, India and China are one of the largest R&D locations. Although in recent years wages in these regions have increased significantly, slightly relocational drivers to these regions. According to the companies, attractive regions are also found in other emerging economies like South America where skilled personal is located. In addition, the companies prefer fast growing markets since there are still fewer rules and laws of business than in mature economies. In these markets, there is more scope for action and a greater chance to establish as the market leader. In some subsectors, like semiconductors, a close geographical proximity to the customers’ applications is very beneficial in this context.

Proposition 2) Location determinants and patterns are highly dependent on the type of R&D&I activity (TRL).

Generally fundamental research is more often located in Europe and the USA, while in the later technological readiness stages R&D&I activities are more equally distributed between Europe, USA and the Asia-Pacific region. In the Electronics & Parts and Systems subsector frontend manufacturing is more often located in Europe and America, while backend manufacturing is mostly located in emerging economies of Asia. R&D traditionally was mostly located in Europe. In recent years several R&D sites emerge in Asian technology clusters, but the ones in Europe still remain important.

A final important location driver of R&D activities is the availability of technological capabilities and skills. This is especially important for the more research-oriented activities. These activities will be mainly driven towards developed economies. It is important for firms to be present in relevant industry clusters to learn from customers and competitors about new markets and the application of new technologies in these markets.

Proposition 3) Corporate strategies are decisive in determining the location choices.

The corporate strategy is highly relevant for the location choice. Major drivers for the corporate strategy are the presence in highly innovative ecosystems and technology clusters. Besides that, the presence in fast growing markets is an important locational driver (see proposition 1).

Proposition 4) The extent to which R&D&I activities are collocated with production activities, strongly depends on the type of R&D&I activity involved.

In the case of the company R&D&I activities are not restricted to Technological Research and Product demonstration but extend to manufacturing processes.

In the software market the main reason for this is that specific software usually does not match the product the customers eventually consume. Hence, foreign innovation activities are often collocated with the companies' production activities.

In the Electronics Parts and Systems subsector R&D&I activities are not restricted to Technological Research and Product demonstration but extend to manufacturing processes. The main reason for this is that under laboratory conditions some components like semiconductors usually do not match the product the customers eventually receive due to their sensitive nature. Hence foreign innovation activities in the ICT sectors are often collocated with production activities. Locational decisions depend on the type of R&D&I activity, while much of product Design, technological Research and R&D happens along frontend manufacturing which is mainly in Europe and the USA, the majority of backend manufacturing is located in Asia.

Proposition 5) The organization of R&D&I activities across GVCs is industry/sector specific. Industry differences are observed at the level of the location decision, the impact, the governance mode applied. Even within industry, differences can occur depending on the R&D&I activities (TRL scale) of the company.

In the ICT sector product characteristics hardly influence the organization of R&D&I activities. Transporting costs usually play a minor role. Small fragile semiconductors and electronic equipment usually require a co-location of development and production sites. Software products can come from all world regions and geographic distance is not very relevant, although the presence within technology clusters and proximity to universities and talented employees is relevant for innovation.

- ➔ See also cross-sector analysis

Proposition 6) Outsourcing and offshoring trends are highly industry-specific. The international fragmentation of R&D&I activities is highly dependent on the industry and R&D&I subfunctions/activities or tasks. Highly capital-intensive industries concentrate key R&D&I activities to a larger extent than less capital-intensive industries.

Depending on the subsector, parts of the ICT-industry are highly capital-intensive intensive and relocation costs are high. In the software industry, however, relocation costs are lower. Therefore, an international fragmentation of R&D&I activities around the globe is possible.

Through outsourcing of ICT internationalization of non-ICT sectors is stimulated, too. To the extent the ICT-internationalization effect contributes to income growth, the ICT growth will be reinforced by the demand in ICT-intensive sectors. On the other hand, there exist limiting factors to outsourcing as managerial efforts required in a more complex GVC will rise with the degree of internationalization. International outsourcing and offshoring do relate to ICT goods as well as ICT services.

In the case of international outsourcing there can be both positive and negative income and employment effects on the current account of the home country. Due to high wages in developed countries, firms take advantage of offshoring or outsourcing to reduce costs. The shares of Japan and the United States in world exports of ICT goods halved from 2001 to 2013, due in part to offshoring of production. On the other hand, emerging economies are strongly competing. Decreasing the total contract value and increasing competition from other offshore locations such as Brazil, China and the Philippines have put the revenue growth of Indian IT services providers under pressure.

The ICT sector is special in this regard as it has very high innovation dynamics. Foreign direct investment (FDI) plays an important role so that part the overall ICT sector will be affected by FDI dynamics. Another specificity of the ICT sector respect to outsourcing is the fact that ICT potentially allows a very flexible and fast fragmentation. This implies the risk that individual EU countries could lose value-added at some point in some specific activities of the ICT sector.

On the other hand, EU trading partner firms may outsource to firms in the EU as well and the international competitiveness of EU-firms may significantly be improved through efficient outsourcing, which may have positive economic effects in the long run.

Proposition 7) There are a broad range of corporate governance mechanisms and modes to sustain corporate R&D&I across GVCs. We expect these governance mechanisms/modes to be highly dependent on the type of R&D&I activity/task performed. A trend towards global R&D&I networks (originating due to alliances, collaboration and/ or subcontracting) can be observed, although they are often difficult to manage. The corporate strategy will however be determinant for the decision on the governance mechanism.

The interviewed companies source strategic knowledge through its open innovation network wherein they engage in strategic alliances with key partner firms. Within these alliances, knowledge diffusion is highly stimulated as firms work closely together.

Patent cooperation and patent pools with competitors and suppliers are common. Within these alliances, knowledge diffusion is highly stimulated as firms work closely together.

Proposition 8) The impact of the offshoring of R&D&I activities on the home or host country mainly occurs via increased productivity and innovation performance. This is however highly dependent on a set of contingences related to the firm's embeddedness and technological capabilities.

Foreign innovation activities significantly increase the knowledge of ICT companies in these regions. This knowledge refers to all kind of host region drivers like intellectual property laws, practices of the regulatory, tax, judicial and administrative bodies, regional economic and geopolitical developments, technological strengths and weaknesses, recruitment of skilled employees in these regions.

Overall a Win-win situation can be established in many cases, where both the host and home region benefit.

Proposition 9) The home-base augmenting R&D argument is increasingly important in the location decision of companies. Home-base augmenting R&D will have a stronger impact on the innovation performance than home-base exploiting R&D.

This proposition holds for the interviewed companies. Fundamental research still occurs in traditional IT markets like Europe and the United States.

In the Electronic Systems & Parts subsector "proximity to application" highly relevant. Thus, more and more customers are located in Asia. A lot of relevant knowledge for the R&D activities in Europe can be generated by experiences at the sites in foreign countries.

Proposition 10) The government can play an important role in attracting/sustaining R&D&I investments, by focusing on improvements of the infrastructure, cost-related aspects and the legal and political (stability/continuity) environment.

Governments can play a role in determining locational choices. Varying practices of the regulatory, tax, judicial and administrative bodies, intellectual property rights and policies affecting trade and investment aimed at limiting free trade play a role for locational decisions outside of Europe. Foreign programs like "Made in China 2025" are expected to have effects customers and global value chains. European programs supporting companies, e.g. in the segment of microelectronics like facilitated support in the funding of IPCEI are welcomed.

A major locational decisions driver in the software industry today are labor costs. In some instances high labor costs in Europe could reduce its competitiveness, although wages of high skilled IT-personal In emerging markets have recently grown significantly, alleviating this effect.

In most cases, there is less concern about intra-EU outsourcing than about extra-EU outsourcing.

Proposition 11) The competitive environment of the host region can

significantly alter a region's attractiveness.

The competitive environment of the host region may have a positive effect on a regions attractiveness. In the studied cases, the companies benefit through closeness of other IT firms (e.g. in Bangalore and Silicon Valley). This allows collaborations and provide resource pool, for example team building is more efficient.

On the other hand, for ICT-companies that have achieved the position of market leadership in most of their core segments, competitive environment of the host region may only have a limited influence.

Proposition 12) Knowledge spillovers and technology transfers are mainly driven by the governance mode, TRL level and government stimuli.

The TRL level and government stimuli are only partially relevant for knowledge spillovers. R&D is relatively independent from TRL as borders between TRL are highly blurred due to high degree of R&D integration within the manufacturing process. The emergence of clusters is highly technology and market driven. Infrastructure and the overall competitive environment of the host regions, however, plays an important role (see above).

Proposition 13) The common fear that R&D&I internationalisation is hollowing out domestic innovation is unfounded.

In the case of the selected companies, R&D&I activities are partially offshored due to high labor costs in the home region. Hence, foreign R&D&I operations might strengthen foreign innovation. In addition, the relocation from Europe to other world regions could result from rapidly growing markets in other world regions and the fact that "proximity to application" is crucial for the firm's businesses. The speed of market growth in the ICT sectors is closely related to demographics and the age of potential customers.

On the other hand, political and economic stability play an important role, preventing relocation to certain foreign markets. In addition, R&D&I operations of IT companies are complementary with domestic innovative activities. New technological trends like "industry 4.0" further increase productivity of European workers and enhance the attractiveness of locations in Europe. One possible cause for relocation from Europe to other world regions, however, could result from rapidly growing markets in other world regions.

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