Final Report

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Analysis of the evolution of the costs of research – trends, drivers and impacts

Study commissioned by DG Research & Innovation
Contract: RTD/B2/2009/COST-2009-01

Project consortium: AIT (AT), CERIS (IT), CMI (FR), GC (BE), GT-TPAC (US), UNU-MERIT (NL), UNIMAN (UK), NIFU-STEP (NO) (Partners of the ETEPS Network)

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of the Study “Analysis of the evolution of the costs of research – trends, drivers and impacts”

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The ETEPS AISBL European techno-economic policy support network has been set up on the initiative of the Institute for Prospective Technological Studies (IPTS) of the European Commission. Its main mission is to provide intellectual services for carrying out techno-economic and policy-related studies in the context of EU policy-making.

The ETEPS network is organised as a legal entity the ETEPS AISBL, founded in 2005 by 19 effective members from 15 EU Member States. It further counts 19 associated members worldwide and is supported by a network of external organisations.

The main activities of ETEPS are:

- Undertaking scientific research on the interdependencies between science,
- technology, economy and society, with a focus on foresight and evaluation;
- Developing and using scientific models, data and other related tools to improve the
- scientific understanding of European Science & Technology related policies; and
- Taking appropriate actions to disseminate the knowledge thus gained.

Brussels, December 2011

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1 Executive Summary

Statistical data and studies suggest that investments in research have grown in the past decades in many industries in Europe. However, there is little empirical evidence about the drivers of private sector research investment growth. On the one hand, the rise in input prices such as salaries or costs of new equipment such as microscopes accounts for some of this growth in private sector research investments. On the other hand, companies are spending more to capitalize on emerging market opportunities. Certain sectors such as the pharmaceutical industry claim that conducting research has become ever more costly and refer for instance to the cost of development of a new drug, which has become five times as expensive as 20 years ago. With this study we examine for the first time through **comprehensive field research the drivers, development trends and consequences of increasing research costs in Europe**. The resulting information about the evolution of the costs of research contributes to a better understanding of the strategies chosen by public and private R&D performers and the effect of policy actions such as the creation of the European Research Area.

The study combines different **methods ranging from analysing statistical data sources, employing a survey, performing case studies and developing scenarios** of the likely consequences of rising research costs. A key element of the study is an empirical survey of industrial firms and public research organisations (PROs) by means of a mail questionnaire and interviews with representatives from companies and PROs. The survey sample targets 2,000 Industrial R&D Scoreboard firms (including the largest R&D performing companies located in Europe in manufacturing and service sectors) and 500 Public Research Organisations. Respondents to the survey consist of 103 companies from different sectors representing the most important European private R&D spenders (in significant research-intensive sectors such as ICT, Automotive and Pharmaceuticals) and 64 small and large PROs. The case studies cover the research cost issues in 16 European and 5 non-European large multinational, R&D intensive, companies and 16 European PROs.

The empirical study confirms that **research costs have grown in the past five years, on average by 47% across all industries**. **Wage costs** are the most important element of R&D cost, accounting for 50% of all cost in companies and 62% of the costs in PROs. Despite wage increases across many organisations, wage costs are not regarded as the most significant contributor to increases in R&D cost. Sixty percent of companies surveyed reported that, in the last five years, the **main R&D cost increases were due to increases in capital costs** (investments in infrastructure, machines, etc.). Similarly, 35% of PROs reported that the largest component of R&D cost growth over the last five years has been capital costs. Compared to firms, PROs spend less for capital costs and for purchasing R&D. In the future, companies expect that particularly costs for purchasing R&D (48%) and cost of financing (41%) will grow in the next five years.

There is no common understanding of how to define research costs, however, from an economic perspective, **research costs can be considered to be the product of (input) price and volume**. This has been adopted in the study. We asked companies to assess whether research costs have primarily grown due to price (e.g. cost increases due to an increase in wages per researcher) or volume (e.g. increases in the number of researchers). Taking into account this distinction, the results reveal that **total research costs have grown mainly due to a volume effect**.

The same holds for capital costs (e.g. machinery) and material and purchased R&D services. In contrast, the costs of obtaining finance and patents have grown in the past mainly due to an increase in prices.

There are also some differences between sectors: the automotive sector emphasizes growth in the cost of materials and supplies over the past five years; pharmaceutical companies expect rising financing costs; ICT firms expect rising patenting costs. PROs expect that all research cost elements will in the future grow mainly due to price rather than volume, suggesting that PROs are rather sceptical of their ability to expand activities. Overall, survey respondents expect that research costs will increase by only 30% over the next five years (still mainly volume-driven), less than what was experienced in the previous five years. In other words they foresee a **slowing down of the dynamic development over the past five years.**

In the future, cost elements with the highest growth rates include the cost of purchased R&D services by 48% (mainly volume effect) and the cost of financing by 41% (mainly volume effect). The former percentage represents an even stronger trend towards open innovation and a shift in where research is performed rather than an overall increase. The latter percentage shows that the cost of financing research (e.g. in the venture capital market) will become more important.

The survey also examined whether **cost structures vary between different R&D locations** within the (multinational) firms in the survey. Surprisingly, we found that **wage costs do not significantly vary** as a proportion of total costs between the 'main world region' and 'most dynamic region' in which the companies operate. The market for highly skilled international researchers has become a global market with globally comparable wages, a result which was also confirmed by the case studies. However, purchased R&D is much less common in 'dynamic regions' than in 'main location' which perhaps indicates that R&D services are still less developed in emerging and catch-up countries or that the role of research centres in these countries is still being established. In this context, the survey reveals further that the trend to spend more on R&D in Non-EU-15 countries, particularly in Other EU 27 countries, US, Canada, China and India, will continue. Moreover, 'going abroad' is not seen as an important strategy to reduce R&D costs.

Although **transferring research to other lower cost locations was not considered very important for containing research costs, improving worker productivity and collaborative networks were regarded as the most important approach to addressing the challenge of increasing research cost.** Applying for subsidies and tax incentives were viewed as being of modest importance in managing research costs. PROs stressed the importance of eliminating less important R&D as strategy to deal with rising research costs and a more competitive market environment. In addition, PROs particularly claimed that they increasingly run the risk of having difficulty in funding their research infrastructure, which should be addressed by policy makers.

Increasing complexity of the R&D process – which was considered the most important driver of research costs in the surveys – **reinforces the need for collaboration**. There is an increasing need for multidisciplinary projects and the fusion of technologies and research strategies (e.g. bioinformatics and electro-mechanical). The scale of R&D projects and the duration of the R&D process also were considered to be important drivers of research costs.

The most important driver of research costs in the surveys was found to be the i**ncreasing complexity of the R&D process. This reinforces the need for collaboration since**

collaboration facilitates specialisation in R&D capability and sophistication. There is an increasing need for multidisciplinary projects and a fusion and evolution of different technologies and research strategies (e.g. bioinformatics and electro-mechanical) to address potential application areas. The scale of R&D projects and the duration of the R&D process are effects arising from increasing complexity and were considered to be important drivers of research costs.

The PROs survey revealed that increased competition drives the **costs involved in applying for grants and subsidies** higher and higher. The high costs for PRO's regarding applications and reporting for public funding should be addressed by policy makers. The **availability of qualified researchers** (which depends on market prices and is not limited to salary plans by the government) was considered a specific driver for PROs as well.

Interviews with managers suggested that **spending on research was not considered as a cost per se, but rather as an investment**. Thus, decisions about research investments and budgets are based on expected outcomes, risks and strategic competence development. Although cost indicators are used for strategic research management, companies were rather cautious in their use to due to the difficulties of measuring the outputs of research. However, research costs are a factor in many firms, becoming more significant in special and typically disruptive circumstances – e.g. when the business is downsizing. This means that the intelligent focusing of research activities and R&D management methods can have a much greater effect on the value and impact of R&D than cost reduction within the R&D department.

All in all, the empirical evidence of the study shows that companies use very different strategies to cope with rising research costs. The study illustrates that research choices are not so much driven by the direct cost of research, but rather by an assessment of the return on investment that can be realised through different types of research. One key issue that therefore emerges is the need for **policy makers to help strengthen ways of appropriating the returns from research spending** while at the same time being alerted to the importance of adequately allocating costs to different research activities and stages.

Policy should support networks and collaborations. Cooperation should be enabled, preparing researchers for dealing with complexity and trends toward greater multidisciplinarity in research. New business models to support variety in the system when promoting networks and collaboration are also needed, and this means also less bottom up projects and more programmes based on networking or promotion of true networks. Encouraging the mobility of researchers while also providing incentives to 'return home' will be important as well.

The study delivers further evidence for a **changing paradigm of doing research characterised by multiple diverse collaborative arrangements, new funding and business models**. Supporting collaborative research should therefore go hand in hand with measures to mitigate such costs by developing new structures and tools for collaborative research of this nature. However, policy implications cannot simply be identified in terms of how costs can be reduced. Instead policy has to take a more holistic perspective of understanding how cost developments and their impact on strategic choices will affect European productivity and competitiveness.

2 Introduction

2.1 Background and motivation

Investments in research have increased in the last two decades in almost all industries and scientific fields. Figuring in research investment decisions are cost considerations. Research cost structures differ considerably between industries and disciplines and have an impact on the organisation of research and the decisions about where geographically this research should be located. In some fields such as energy research or nanoelectronics, heavy investments in equipment or clean rooms are needed. In other areas, research costs consist mainly of personnel costs. Moreover, high research costs for equipment in particle physics or trials in pharmaceutical research also implies that research can only be organized in co-operation between countries, firms and research organisations. Differences in the cost of research between countries may have an increasing effect on the decisions of multinational enterprises about where to locate research functions. The availability of high-skilled research personnel in low-cost locations such as India, China or other parts of the world may increasingly influence the internationalisation of research and change the profile of research activities in Europe.

Official statistics distinguish between labour, capital and other current costs. Statistical data reveal, for instance, that the share of labour cost has remained unchanged while capital costs have declined in the last two decades. Despite a poor coverage of countries (especially the BRIC countries, but also many EU15 countries) and industries in these statistics, their trajectories reasonably suggest that there are wide variations between countries and sectors with regard to research cost structure and development. However, reasons for the increase and changing research cost patterns are not offered by statistics and many data gaps exist around countries and sectors.

Besides a lack of empirical and statistical data there are weaknesses in the ability of existing theories to explain sufficiently the differences between sectors and countries, their interdependencies and the determinants of the development of research costs.

The costs of research are an important motive behind the vision of a European Research Area, which - at the end - should reduce the transaction costs of international projects, increase competition, and raise productivity in Europe. Information about the evolution of the costs of research helps to understand better the strategies chosen by public and private R&D performers and the effect of policy actions such as the creation of the European Research Area.

The aim of this project is to shed light on the evolution of the costs of research, including its main components, time trends, and differences between research costs, between sectors and countries, and between different types of organisations. The cost of research study (COST) looks into the evolution of the costs of research, its main drivers, and the effects of its likely future development on the competitiveness of Europe and EU policy.

2.2 Research questions

The research questions in this project are all related to the impact of costs variations in the past, and in the future, in private, and in public research organisations. This project also examines the impact of research costs on competitiveness, productivity and attractiveness of doing business.

More specifically, the COST project addresses the following research questions:

1. **Whether, to what extent, and why the research costs have increased over the past two decades?**
2. **Whether, to what extent and why the costs of research can be expected to increase over the next decade?**
3. **What are the main strategies suggested by key practitioners in dealing with the evolution of the cost of research?**
4. **Whether, and to what extent, the cost of research and its expected evolution will affect the EU economic landscape?**

The study thus looks not only at past development of research costs but also takes into account likely future developments in the cost of research and the implications of these developments for productivity and competitiveness. The study builds up an improved base of knowledge about the complex drivers of research costs.

The research undertaken is progressive and first starts with the identification of the major components of the costs of research, and then identifies relevant drivers of those components. In order to address the question of impacts we also have to better understand how the important research performers deal with rising research costs and hence deal with managerial and organisational strategies.

2.3 Methodology of the study

The study employ a number of methods to address the research questions. These methods range from desk research, analysing statistical data, to conducting a survey, to case study composition, and scenario development. While statistical data and published studies allow to examine the past development for a longer period of time, by the empirical study we investigate the development of the past five years, a period time for which companies were able to give reliable information.

A key element of the COST study is an empirical survey in industrial firms and public research organisations (PROs) combining the organisation of survey based on a standardised questionnaire and conducting case studies.

The survey comprises a study on the **2,000 Industrial R&D Scoreboard** firms and **500 Public Research Organisations** based on a standardised questionnaire. The Industrial R&D Scoreboard it constructed and updated regularly based on a survey coordinated by the IPTS. It contains the largest R&D performing companies located in Europe in all manufacturing and service sectors. Both questionnaires have the same structure and a set of common question items which allows direct comparisons.

The **case studies** cover the qualitative study of 16 European and 5 non-European firms and 16 European Public Research Organisations (PROs). The companies chosen for case studies are large multinational, R&D intensive, companies identified via the EU R&D Scoreboard. PROs are more varied because of historical national variations in R&D and innovation systems but are prominent R&D establishments. The PROs were selected because they are significant in their national context and were considered interesting to illuminate particular aspects of R&D organisation potentially relevant to costs. Some PROs have a strong international or global presence in their field but do not tend to have international locations.

The development of costs differs between regions. An adequate treatment of this challenge hence requires a broad coverage of countries to be studied by the project team. We therefore not only investigate companies located in Europe but also conduct selected case studies in the US and China.

While the company sample is clearly defined and rests on the R&D Scoreboard firms, the selection and definition of **Public Research Organisations** (PROs) is less obvious. Different definitions can be found in the existing literature: Hales (2001), for instance, defines Research and Technology Organisations (RTOs) *"organisations with significant core government funding (25% or greater) which supply services to firms individually or collectively in support of scientific and technological innovation and which devote much of their capability (50% or more of their labour) to remaining integrated with the science base"*. Research centres, in the definition given by PREST (2002) are *"National, nonuniversity public or semi- public research institutes as well as institutes from the non profit foundation sector "where government was the major customer or the driving force behind their creation and existence".* Another definition is given by The Frascati Manual (OECD 2002) and includes: *"All departments, offices and other bodies which furnish, but normally do not sell to the community, those common services, other than higher education, which cannot otherwise be conveniently and economically provided".*

The definition of Research Centres from PREST (2002) best fits this project because it also includes the Research and Technology Organisations. Even when they partially rely on commercial income, government is the major customer or the driving force behind their existence. Public research organisations are hence defined for the purpose of this study as national, non-university public or semi-public research institutes as well as institutes from the non profit foundation sector to the extent that government is the major customer or the driving force behind their creation and existence.

Two core issues have thus be considered in choosing the definition of PROs, i) to deal with organisations that have an autonomous budget, and ii) to deal with organisations whose primary goal is to perform research (and not teaching).

We consider as PROs' unit of analysis the institute (not research team, neither larger institutions). Multidisciplinary, multi-organisational institutions, such as CNR, CNRS, and Max Planck are excluded, but a single institute of these organisations can be selected.

In addition to the empirical study we also constituted an **expert group** of 12 high profile R&D experts and professionals. The expert group made a contribution in the analysis of the evolution of drivers and the discussion of the impacts of the evolution of the research costs for the European Economy. The experts participated in two workshops to i) validate the analytical framework, and ii) discuss the most likely evolution of the costs of research and its components and their potential impacts on company strategies and policy makers' interventions.

Building on the analysis of the survey and case studies, we employed a **scenario method** to develop an understanding of how the identified changes might play out over the years ahead and impact on the further development of R&D activities in Europe.

The first step in developing the scenarios consisted in exploring linkages between sets of drivers of the costs of research. The case study material was used to identify groups of drivers for change and correlations between the individual drivers. The case studies therefore represent the key source of evidence that informed the development of the scenarios.
The process of identifying linkages and interdependencies between drivers was helped by asking all researchers involved in the case study interviews to identify whether there was a

strong, weak or no link between each pair of drivers. This helped ensure that, where a scenario related to a specific driver, the interactions with other cost drivers were picked up adequately. The high-level drivers were expressed in terms of specific management challenges that arise as a result of changes occurring in the R&D environment. This analysis was underpinned by collecting specific driver evidence to build a number of scenarios. Developments regarding the costs of individual inputs (e.g. labour, equipment, facilities) were considered as a secondary element of the scenarios that seek to discuss the interactions between the strategic drivers and such cost components. Broad strategic drivers for doing research in Europe therefore provide the main structure and content for the reflection.

The scenarios developed in this way were circulated to members of the expert group in preparation for the second expert workshop. The deliberations of the expert group focused on three main themes, namely:

- Reviewing the scenario evidence
- Identifying policy and strategy implications and
- Discussing recommendations

The results of the expert workshop were then integrated into the final driver evidence and the scenarios as presented in this report.

2.4 Definition of research costs

The core subject of this project is the cost of research. To address this subject we firstly have to answer the question, how research costs can be defined and measured? Here we present some initial definitions although we will suggest and explore different definitions and perspectives in the course of the project. To some extent, the concept and definition of research costs is dependent on the perspective or profession of the audience. Accountants, economists, business managers and policy makers each may have different definitions and interpretations about what makes up research costs.

The literature provides different definitions of research costs. In the **OECD Frascati Manual**, for instance, based on the well-known categorisation of different research activities (i.e. basic research, applied research, experimental development) R&D personnel, current costs, and capital costs are defined as separate R&D cost categories. While the Frascati Manual extensively defines what are R&D activities (and what not) there is no explicit distinction between R&D expenditures and R&D costs. The Frascati Manual defines (intramural) R&D expenditures as measure of R&D input as *"all expenditures for R&D performed within a statistical unit or sector of the economy"* (OECD 2002, 108). For R&D purposes, both current costs and capital expenditures are measured and the OECD distinguishes further between "current costs" and "capital expenditures." Labour costs and other current costs (e.g. material, overhead) together make up current costs. Regarding capital expenditures, land and buildings, instruments and equipment, and computer software are distinguished (OECD 2002, 108). As measure of volume the OECD proposes to collect data about the number of R&D employees: *"While data series measuring the number of R&D staff, and notably researchers, have many important uses, they are not a substitute for a series based on the number of full-time equivalent staff. The latter is a true measure of the volume of R&D and must be maintained by all member countries for international comparisons"* (OECD 2002, 99).

These are useful for statistical purposes at a national level but neither fit how business managers might prefer to analyse their costs nor is adequate to address our research questions to examine the drivers, development trends and consequences of increasing research costs in Europe.

Moreover, the R&D expenditures reported by many large companies reflect corporate strategic decisions to invest at a specified intensity and for business development reasons. This will depend on the type of industry, business and economic conditions and competitor activity, and will not closely track changes in actual or unit costs. If the latter change over time then the volume of R&D and the composition of the R&D portfolio can both be adjusted to compensate without changing the level of expenditure. For the case of public research organisations the funding available to is set by government budget allocations which in turn depend on economic and political factors and scientific purpose rather than detailed cost information.

Although the focus of this project is on the development of research, that is basic and applied research according to the OECD definition, in this project we talk more broadly and often use the term R&D. This is due to the fact that studies and statistics often reveal or deal only with R&D and do not differentiate research (R) from development (D). Moreover, research performing agents of an innovation system such as companies and public research organisations often do not distinguish clearly between both activities. We hence use R&D as term mostly throughout the report, though, we focus on research – the R of the R&D – whenever possible.[1]

Other definitions of R&D are provided within the **accounting literature** and by accounting standards for the purpose of determining how to treat different types of accounts. The accounting field defines fundamental cost categories such as labour costs, material costs and capital costs, which are used in cost accounting and financial reporting. The use of these types of standard definitions enable data provided in firm accounts and financial reports to be aggregated to the national level. The International Accounting Standards (IAS), for instance, distinguishes between research and development activities in the following definition: *"Research is original and planned investigation undertaken with the prospect of gaining new scientific or technical knowledge and understanding."* In addition, in relation to a possible capitalisation of costs, IAS reports that: "*Cost is the amount of cash or cash equivalents paid or the fair value of other consideration given to acquire an asset at the time of its acquisition or construction, or, when applicable, the amount attributed to that asset when initially recognised in accordance with the specific requirements of other IFRSs."*

The term expenditures is worth discussing in the context of our topic. Official statistics, for instance report (correctly) about R&D expenditures. Accounting literature deals with the terms cost and expenditure and the possible differences between the two: Expenses are generally defined as the use and consumption of resources in the process of generating revenues, expressed in terms of money. While financial accounting (e.g. balance sheet, profit and loss account, cash flow statement) use the term expenditures, cost accounting uses the term costs, thereby referring to more accurate (timely) data based on actual prices and somewhat different valuation methods (current costs versus historical costs). Thus, cost is the amount of cash or cash equivalent paid or the fair market value or other consideration to acquire or generate an asset. However, the terms cost and expenditure are not always clearly defined and differentiated. Sometimes they are used interchangeably, and their definition depends also on national accounting standards and rules.[2]

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1 In this study the emphasis is on research rather than development. Typically, in many industries, research is less expensive than development and so comprises a smaller proportion of the overall portfolio. Nevertheless, for more than ten years businesses have preferred to minimise the risk of failure and have chosen to invest less in internal research and to invest more in shared and collaborative research, including outsourcing to universities.

2 While, for instance, in German speaking countries costs and expenditures are clearly separated in many other countries costs and expenditures are used often synonymously. IAS 38.65, for instance, defines, *"the cost of an internally generated intangible asset … is the sum of expenditure incurred from the date when the intangible asset first meets the recognition criteria …"* hence defining cost as the sum of expenditure.

An **accounting based definition of research costs** referring to the mainstream literature could thus be formulated as follows: "The use and consumption of resources in the process of original and planned investigation undertaken with the prospect of gaining new scientific or technical knowledge and understanding, expressed in terms of money."

However, many people associate with the term cost the "unit cost" of an activity in the sense of "what does it cost?" Obviously it is more difficult to say what a unit of research is, compared to, for instance, what the costs are to produce a screw.

Defining R&D activities including the cost categories is one dimension of the definition. In addition, other costs attached to the quality of research, the cost of managing a research process or project, the spillovers from other R&D activities, and the support of the government or public research organisations have be taken into account when measuring and valuing research costs. Moreover, R&D costs and their composition vary widely in size and nature among the sciences and sectors of economic activity.

From **the management perspective** the definition of cost is quite different. The management approach, as distinct from the accounting approach which values the inputs used up in the process, focuses on costs given strategic and organisational constraints. Under the management approach, R&D processes count as costs incurred in the development and maintenance of the core competences.

Thus, although business R&D expenditure covers actual costs over a period of time (usually the annual reporting cycle)[3], it is not simple or accurate just to use R&D expenditure trends as an indicator of cost trends. The volume of R&D changes for various reasons: businesses expand and contract according to economic conditions and management performance; mergers and acquisitions dramatically change the size shape and R&D intensity of companies; R&D foci are changed as technology and innovation prospects are re-evaluated; the characteristics and scale of R&D work changes – usually becoming bigger – as projects progress along the innovation pipeline; R&D collaborations and open innovation can dramatically reconfigure how R&D is deployed and how R&D costs and innovation strategies are evaluated.

2.5 Conceptual framework

The aim of the project is to examine the development of research costs and its evolution in different environments. The most basic approach to analysing the cost of research is to distinguish between **price and volumes** and characterise cost as the product of the volume multiplied with the price. This approach would require having a measure of the input (such as a person month a scientist's work) of research. Measurement in terms of prices is measuring prices per unit of R&D input. While official R&D statistics revealing data on R&D expenditures following the OECD Frascati Manual do not follow such an approach, within this study we aim to examine the development of volume and prices of R&D costs, i.e. we investigate whether R&D costs are driven by volume (e.g. costs increases due to an increase in the number of researchers) or price (e.g. costs increases due to an increase of the wage cost per researcher) effect.

Moreover, R&D activities should not only be interpreted and assessed focusing on R&D input but would ideally also take into account the R&D output. The cash flow from R&D or from new innovative products would then be the unit of output. In practice this approach is hard to measure directly, using the available statistics. The measurement of the cost of research in

[3] And can be adjusted by what tax authorities regard as eligible for tax credits.

terms of prices underestimates significantly the value of R&D output. It ignores a number of crucial factors impacting the cost of research: the quality and productivity of R&D, the scale and scope effects of the research, technological complexity, the impact of tax credits, subsidies and last but not least the spillover effects from the environment in which the R&D is conducted.

Measuring the cost of research per unit of output is not possible within the boundaries of this project, if it is possible at all. However, one cannot discuss volume effects of the cost of research without taking the output of R&D processes into account.[4] Therefore we have to revert to other means. What we are aiming for is to take “quality” into account by considering the context in which R&D is carried out. In this case quality covers all other factors that impact the costs of R&D in relation to the function it performs within the firm and in relation to the new innovative products that are brought forward by R&D. By quality, we also mean all other characteristics that inputs and outputs can have except volume and price, such as the impact the manager has on productivity and creativity, the spillovers from neighbouring firms and research institutions, the impact of the local and global environment, etc.

In order to investigate the development and the likely future development of research costs we hence **have to examine the context and process of R&D activities and their outputs**. Although, output and quality is hard to measure, we will explore indicators of these concepts to a lesser extent through the quantitative survey, and to a greater extent through the case studies.

In addition, information about R&D costs needs further contextual knowledge in order to make meaningful interpretations. For example, economic policy needs to recognise how business managers are motivated to innovate. The availability, reliability and accuracy of information is important as well as the period to which it refers and any disruptions or special circumstances in that period. It might need to be focused nationally or regionally, on particular industries or technologies, or on business in general. Hence the detail and context (or resolution) of cost information is important. In this study we aim at a conceptual understanding and an appreciation of R&D costs, to clarify and if appropriate to propose measurement and monitoring methods rather than to assemble a comprehensive database of specific cost trends classified by industry region or technology.

In addition, we seek to provide a better understanding of the drivers for the research costs and therefore distinguish between **internal and external drivers** of the cost of research and development of the firm. The internal drivers include direct operational inputs which can be distinguished in a volume and a price component, and the quality of R&D and the way the process is organised and managed. Internationalisation and organisation has a real impact on the cost of research and cannot be ignored in the analysis.

Building on these arguments the study examines the following four factors (see also Fig. 1):

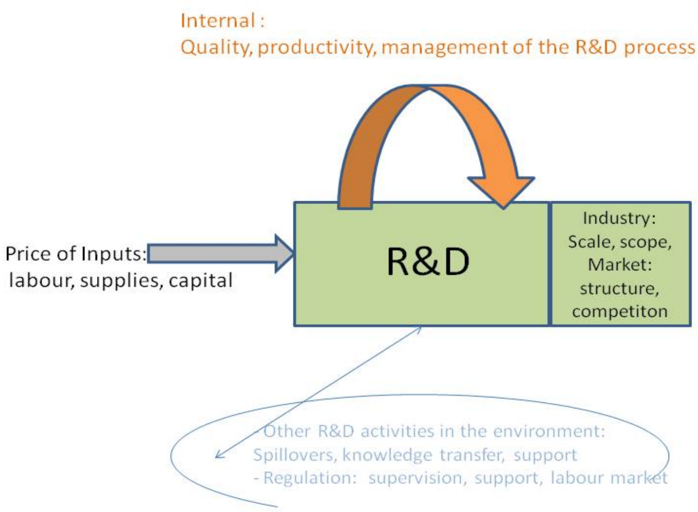
Factor 1 (price of the inputs) covers prices, quantities and qualities of the inputs on R&D. R&D costs can hence be disentangled into prices, volumes and qualities. The price of R&D is not only influenced directly by the price of the inputs (such as cost of labour and capital) but also by the internal organisation and efficiency of the research process. We therefore extent the current categorisation of R&D expenditures used within statistics (e.g. labour costs, other current costs, capital costs) and introduce additional cost elements (e.g. costs for obtaining

4 This can be, for instance, the number of patents and quality effects of patents as indicators of the number and quality of innovations.

patents). For each cost category, we assess the price and volume effects which comprise the evolution of research costs.

Factor 2 (quality and productivity[5]) is related to outputs and productivity of research activities. Research is transferred into innovation and new products and assessing the output of research has to take into account this process which ultimately also depends on the market the firm is competing in. The complexity is due to the subsequent phases found in the literature: i) productivity and quality of the R&D process, ii) launching costs and market reception of new products and iii) market reception (the reaction of the competitors). This latter factor is related to research question (3) and the impacts of current and forecasted costs of research on productivity and competitiveness. To simplify we deliberately have chosen to focus the first phase on the quality and productivity of the R&D process itself and not on the returns and rewards at the end of the innovation cycle. This focus also allows us to address the question whether there is a trade-off between cost and quality of research.

Figure 1: The analytical framework: components of the cost of R&D.



Source: Own depiction

Factor 3 (industry: scale and scope of market competition) collects the important aspects of the impact of market and industry environment and thereby identify the most important external drivers of the cost of research.

Factor 4 (impacts from the environment) encompasses all other relevant impacts, that are thought of as spillovers from the environment. These spillovers take a very prominent place in the innovation economic literature but are in general hard to capture and quantify but are

5 Productivity has been defined in economic literature and different forms of productivity have been proposed. In the simplest form it is a measure of output from a production process, per unit of input. Labour productivity can, for instance, by defined as output divided by labour hours (e.g. value added / hours worked) measuring the output per labour hour.
Related to this definition is a unit cost, which is calculated by dividing the total costs by the number of units. For labour, for instance, unit labour cost haven been defined as total labour cost divided by outputs (e.g. hourly labour costs / output per hour). Both measures are related, and increases in productivity, for instance, lower unit costs.

essential for understanding the competitiveness of a firm in the domestic as well as the global market.

To summarise, in view of the fact that **it is not simple or accurate to use "R&D expenditure" trends as an indicator of cost trends**, in this study the "costs of research" have been defined as "price per unit research times volume".[6] Our particular approach has advantages over other approaches such as the classical Frascati R&D expenditure approach as it allows to verify statements like "research costs are on the increase". The novelty of this approach is that it allows to distinguish between price and volume changes. Furthermore, a breakdown of cost components of research such as labour, capital, management, financing, etc. allows to compare trends over time and across sectors. Moreover, it is recognised that the frontiers of research and business research objectives are continuously advancing as a result of new equipment and computing applications, accumulated knowledge and expertise, scientific opportunities and emerging technologies, changes in business needs and markets, changes in management methods, R&D locations etc.

The report is structured as follows: In chapter 3 we will investigate whether and to what extent research costs have increased in the past and how they may be expected to evolve in the future and thus address mainly research question (1). Chapter 3 refers primarily to the academic literature, presents some statistical data and uses the data from our own empirical study to answer the research question. In chapter 4 we investigate what drivers have and will affect this development and hence address the why dimension of research questions (1) and (2). We again use findings from the literature and perform analysis based on our own survey and case study material to address these two questions.

Chapter 5 examines the question how do companies respond to increasing research costs and how have their own strategies influenced research costs? This question most directly addresses research question 3. Chapter 6 investigates how companies and PROs measure and assess the development of their research productivity.

In chapter 7 we deal more specifically with the implications of increasing research costs for the economic landscape and research policy. To address this topic, we constituted an expert group and organised a scenario development workshop. The members of the expert group are shown in chapter 12.

In chapter 8 we summarise the main findings from the empirical study, with the findings structured according to the four research question of the COST study.

A policy-oriented summary of the COST study is given in chapter 9. We highlight specific results and discuss them in the context of European Commission policy initiatives, current policy debates and strategic goals at the European level.

Chapter 10 describes in more detail the methods of our empirical study, i.e. the survey of 2.500 organisations and the 37 case studies. The corresponding questionnaires can be found in the appendix.

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6 The “R&D expenditure” reported by many large companies reflect corporate strategic decisions to invest at a specified intensity. This will depend on the type of industry, business and economic conditions and competitor activity, and will not closely track changes in actual or unit costs. If the latter change over time then the volume of R&D and the composition of the R&D portfolio can both be adjusted to compensate without changing the level of expenditure.

3 The development of research costs

3.1 Evidence about the development of research costs based on statistical data

Apart from evidence from statistical sources there is little literature or studies available which have investigated the development of the different components of research costs.[7] We therefore will focus on presenting statistical data to achieve a first picture for the development of research costs.

3.1.1 Data sources

In this chapter we identify the development of different cost components and how they vary between countries and sectors. EUROSTAT data and OECD-data from 27 countries for the years 1997 and 2005. As for many countries data are not available after 2005 we have chosen the period 1997 – 2005 and the years 1997 and 2005 as the reference years for our analysis. In some few cases (i.e. Japan) data was available in the OECD R&D statistics database but not in the EUROSTAT database, and in these cases data have been supplemented with the OECD-data[8]. For the US, data are derived from the database of National Science Foundation. For all databases, data has been extracted from the online databases.

In general, data availability seems to be best for the business sector, where we also have data for UK and USA. Regarding data for R&D expenditures in the business sector, the data used is secondary data, that means data on the aggregate level, e.g. for the whole of the country's business sector not for single firms/enterprises (no micro-data).

The Frascati Manual (OECD 2002) distinguishes between four types of R&D *expenditures.* These are:

- labour costs of R&D personnel (current costs),
- other current costs (current costs),
- capital – land and buildings (capital expenditures) and
- capital – instruments and equipment (capital expenditures).

Labour costs of R&D personnel consist of annual wages, salaries and all associated costs or fringe benefits. *Other current costs* comprise non-capital purchases of materials, supplies and equipment to support R&D. *Capital expenditure* is defined as the annual gross expenditure on fixed assets used in R&D programmes of the research organisation[9]. They should be reported in full for the period when they took place and should not be registered as an element of depreciation.

There are also several options regarding measurement of expenditure: euro, national currency, PPS (Purchasing Power Standard), PPS at 2000-prices or 1995-prices, and euro

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[7] There is much literature on the internationalisation of research using various data sources which is relevant for explain the shifting patterns of research activities which, though, will be discussed in more detail in the subsequent chapter.

[8] When looking at changes in cost drivers over time, we have selected the following 27 countries, which have data for 1997 and 2005, or at least close to these years (e.g. 1998 instead of 1997): Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Iceland, Italy, Japan, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Turkey, UK and USA. When investigating a specific year (2005), the data coverage is wider and includes Croatia, France, Latvia, Malta, Sweden and Switzerland.

[9] Unfortunately, only a small number of countries, notably Czech Republic, Denmark, Hungary, Iceland, Norway, Poland, Portugal, Romania, Slovenia, Slovakia, have separated the two types of capital expenditure for the reference years 1997 and 2005. Instead, total capital expenditure is reported without any subdivision. In the analysis that follows we therefore only consider total capital expenditure.

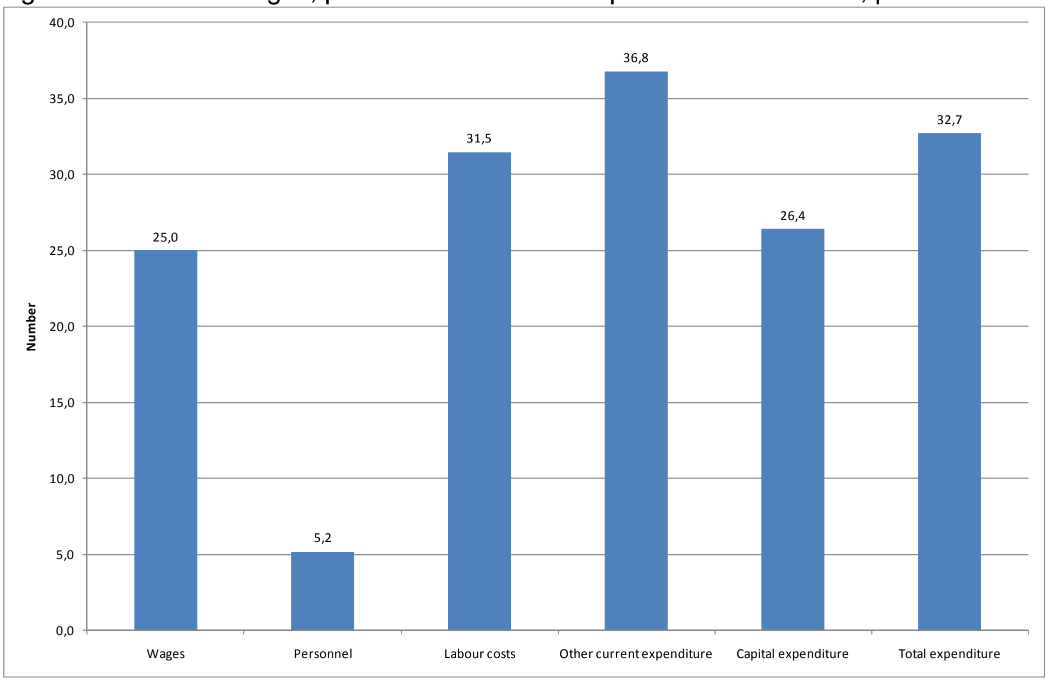
per inhabitant. As a general rule, we have chosen to use PPS at 2000-prices. This should give a measurement of costs (prices) that are consistent across countries, and across time-periods.

3.1.2 Overview of the development

When looking at all countries together, the cost-structure, i.e. the distribution of intramural R&D expenditures by the three major cost categories, has changed little between 1997 and 2005. Capital expenditure has decreased its share from 12 to 10 per cent points, while other current expenditure has decreased by 2 percentage points while the share of labour cost remained unchanged.

Figure 2 shows growth in total R&D expenditure by cost-components and growth of wages, all in PPS 2000-prices. The cost component which has increased the most between 1997 and 2005 is “other current expenditure” (37 per cent). Also the component “labour costs” has increased significantly (31 per cent) and most of this increase is associated with increases of wages (25 per cent) and not of the number of personnel (FTEs). The latter increased only with 5 per cent from 1997 to 2005.

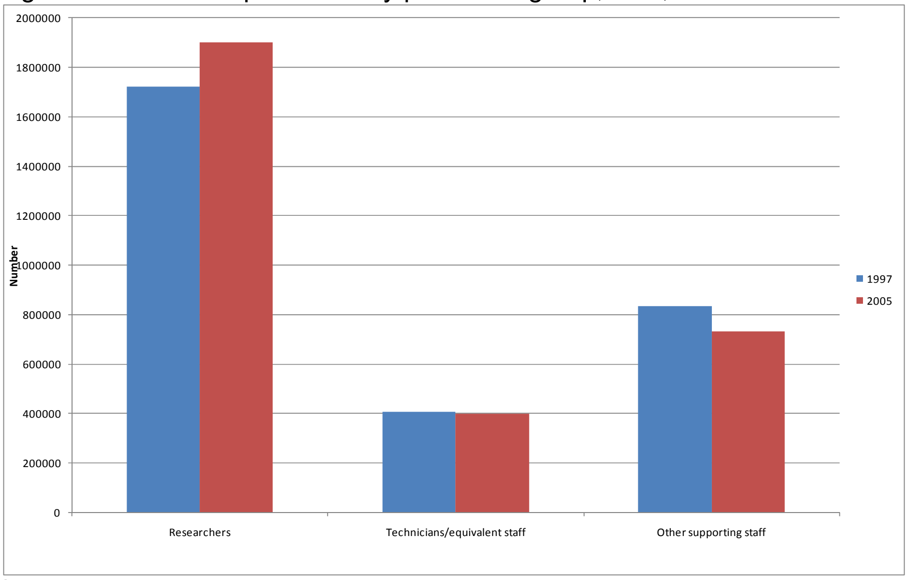
Figure 2: Growth in wages, personnel and cost-components 1997 – 2005, per cent.



Source: Eurostat
Note: all categories are in PPS – 2000-prices, expect personnel: (Full-Time-Equivalents)
Not including Belgium, Croatia, France, Japan, Latvia, Malta, Romania, Sweden, Switzerland, UK and USA. Cyprus, Estonia = 1998.

In Figure 3 we decompose the number of R&D personnel to three types of personnel; researchers, technical staff and other supporting staff. While the divide between the two latter groups may be less accurately reflected in the data available, researchers should be a quite well-defined group. It is also this group that has increased in numbers (FTEs), while there has been a reduction for the two other groups, especially for “other supporting staff”. A possible explanation for this pattern may be outsourcing of R&D activities, which then also may explain why costs grew the most for “other current expenditure”.

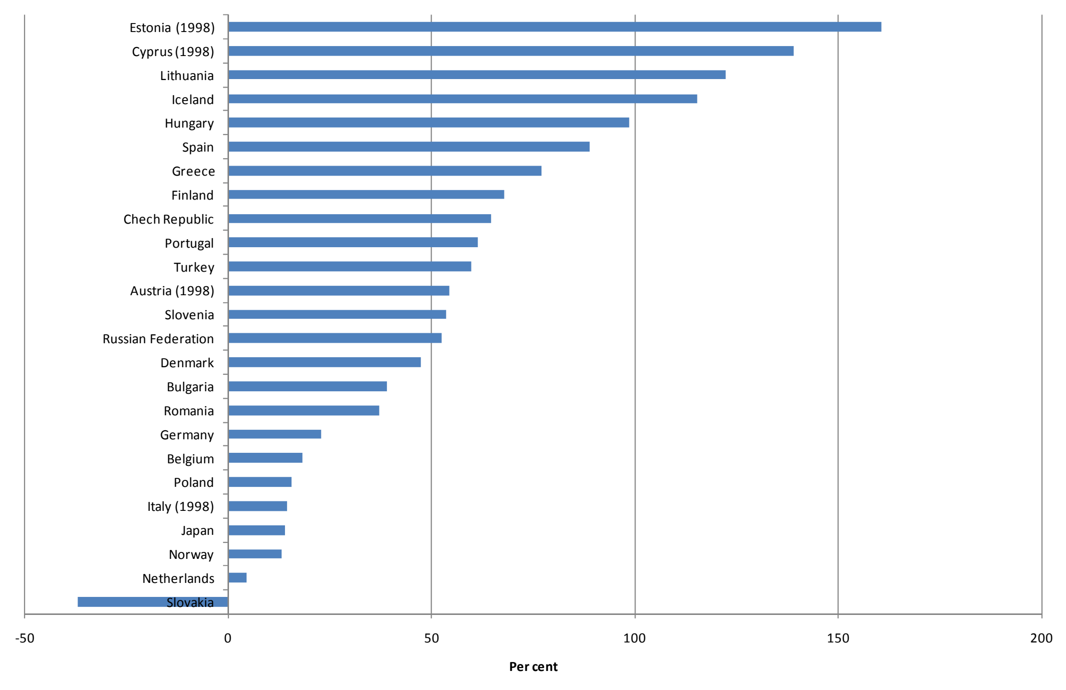
Figure 3: Number of personnel by personnel group, FTE, 1997 and 2005.



Source: Eurostat
Note: Not including Croatia, Denmark, Finland, France, Italy, Malta, Norway, Sweden, Switzerland, UK and USA. Estonia = 1998.

Figure 4 shows increases of total R&D expenditures (GERD) in different countries. We observe remarkable differences between countries. Since the countries are quite different along many dimensions (e.g. size, general economic development, industrial structure, general increase in wages etc), it is difficult to point to specific reasons behind the variations. However, it is obvious that some of the countries with the largest increase are smaller countries that started from a relatively low level of R&D expenditures. Small increases in absolute numbers can thus cause large increases in percent.

Figure 4: Increase in total R&D expenditures (GERD) by country, 1997 and 2005, PPS at 2000-prices.

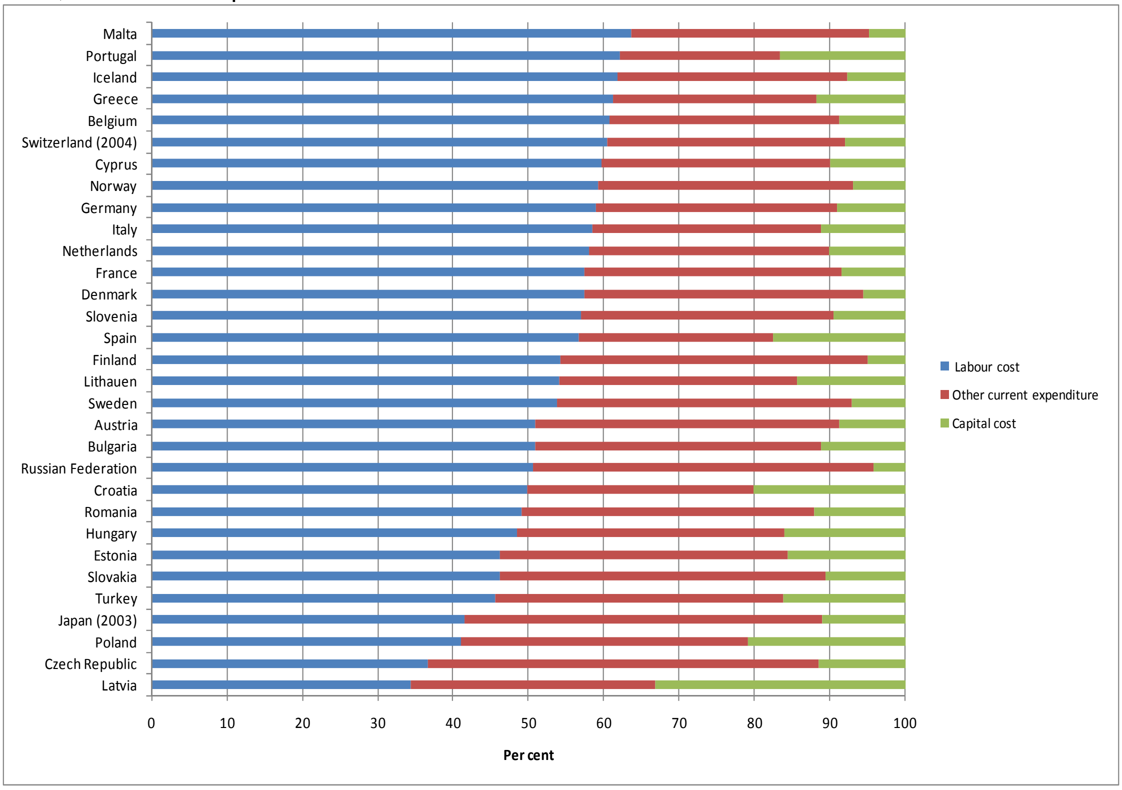


Source: Eurostat

Figure 5 shows the distribution on the different types of expenditure across countries in 2005. We observe quite large variations in the R&D cost structure between countries. Labour costs vary from 34 to 64 per cent of total R&D expenditure while other current expenditures vary between 21 and 47 per cent of total. Labour costs have the largest share in a number of smaller countries, while they account for the lowest share in Japan, Poland, Czech Republic and Latvia. There are also several other new EU27 member states among the countries exhibiting low shares of labour costs compared with Portugal, Greece, Belgium, Switzerland, Norway etc.

We have no good explanation or propositions for explaining why the differences of distribution of total R&D expenditures by the three R&D cost components are unexpectedly large. One would assume – and probably expect – that the composition of the three types of R&D costs is stable between countries, unless the content of research performed (the mix of R&D activities within scientific fields) vary considerably. For example, due to extensive use of laboratories and research equipments, countries with relative large shares of R&D within natural sciences and technology could exhibit larger shares of other current costs and capital expenditures than countries with relative larger research activities, say, in social sciences and humanities. Yet, the pattern observed in Figure 5 seems to partly refute this hypothesis. In the case of Switzerland and Germany for example – both countries with considerable R&D activities in physics, nanotechnology and pharmaceuticals – labour costs dominate and the share of other current cost component is smaller in this two countries than in Czech Republic. In short, we know little about the factors determining when and why the three R&D cost components substitute or complement each other within and between countries.

Figure 5: Distribution of total R&D expenditure (GERD) by cost categories and by country, 2005, PPS at 2000-prices.

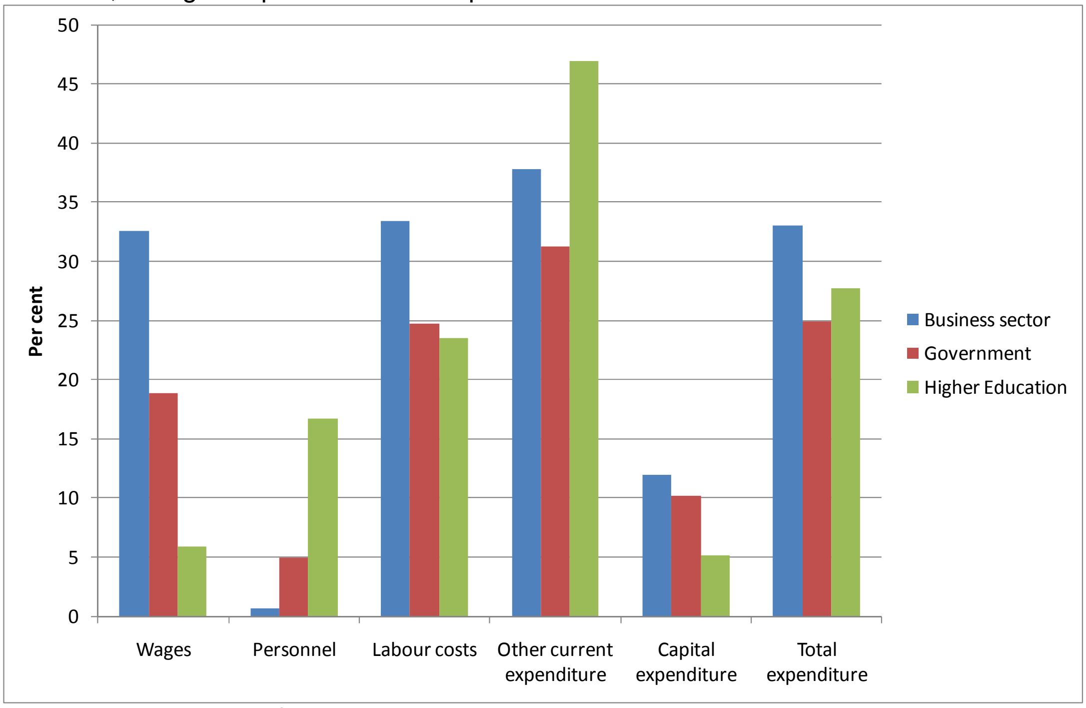


Source: Eurostat

3.1.3 Cost components by R&D performing sectors

Figure 6 shows growth in cost components by R&D-performing sector (business, government, higher education) for the 18 countries where data were available for all the three sectors between 1997 and 2005. The figure shows large differences in the average research wage growth between the three R&D-performing sectors. In the business sector, the average wage growth has been high, while it has been very low for the higher education sector. The government sector lies roughly in the middle between these two sectors.

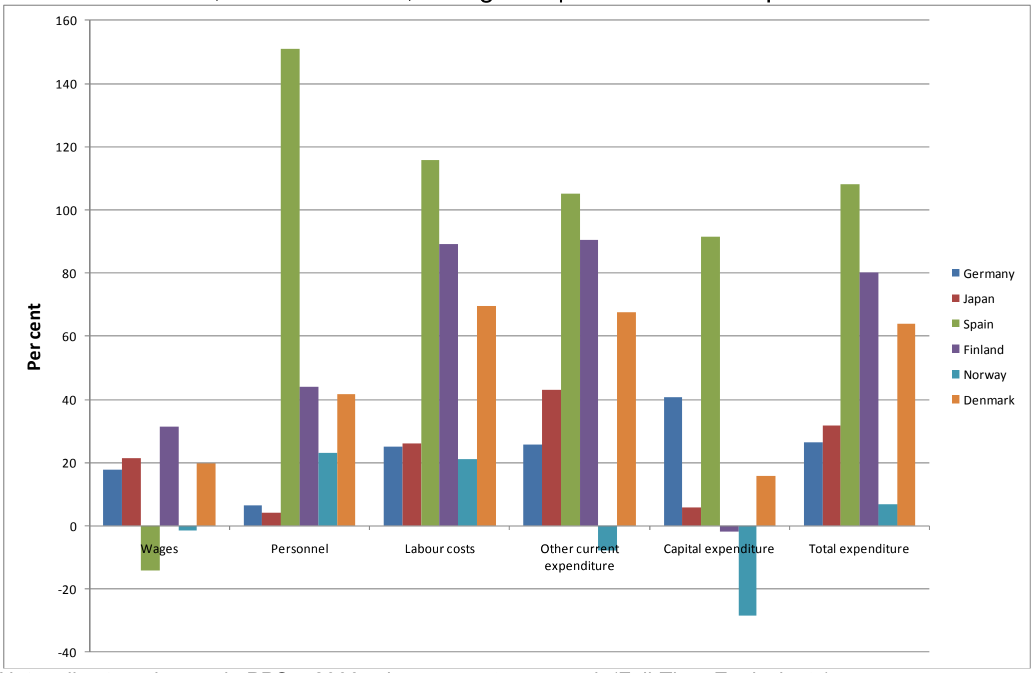
Figure 6: Growth in wages, personnel and cost-components by R&D performing sector, 1997 and 2005, changes in per cent over the period.



Note: all categories are in PPS – 2000-prices, expect personnel: (Full-Time-Equivalents)
Countries included: Germany, Japan, Spain, Finland, Greece, Norway, Denmark, Czech Republic, Hungary, Iceland, Lithuania, Poland, Portugal, Russian Federation, Slovenia, Slovakia, Turkey, Bulgaria.
Source: OECD

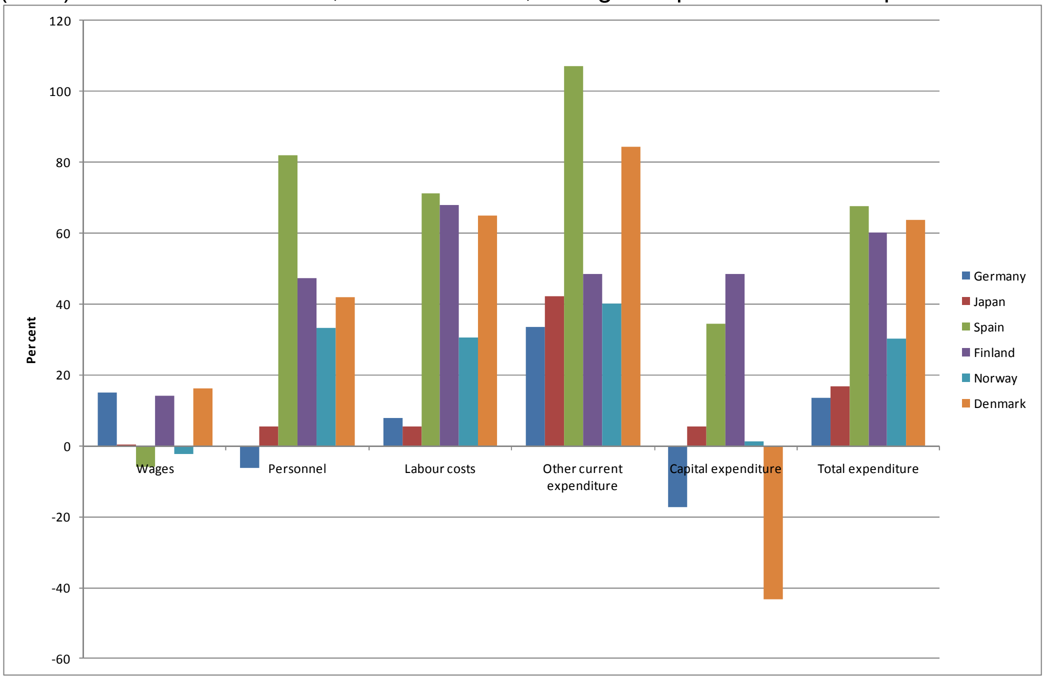
Figure 7, Figure 8 and Figure 9 depicting growth in the cost components for a selected group of countries in the three different R&D performing sectors do not show an equally clear pattern. We still see a tendency towards highest wage growth in the business sector, which was the case for four of the countries, but the differences are smaller than what Figure 6 suggests. We also see that in Spain all three sectors of R&D performance have contributed to the catching-up in terms of R&D expenditures.

Figure 7: Growth in wages, personnel and cost components in the business sector for selected countries, 1997 and 2005, changes in per cent over the period.



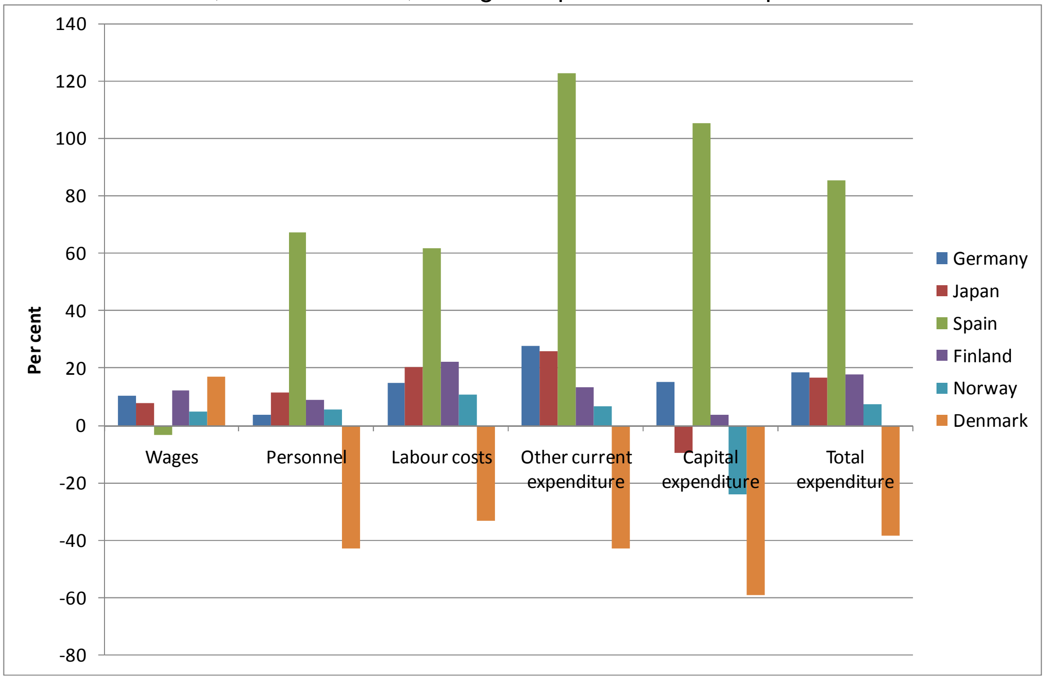
Note: all categories are in PPS – 2000-prices, expect personnel: (Full-Time-Equivalents)
Source: OECD

Figure 8: Growth in wages, personnel and cost components in the higher education sector (HES) for selected countries, 1997 and 2005, changes in per cent over the period.



Note: all categories are in PPS – 2000-prices, expect personnel: (Full-Time-Equivalents)
Source: OECD

Figure 9: Growth in wages, personnel and cost components in the government sector for selected countries, 1997 and 2005, changes in per cent over the period.



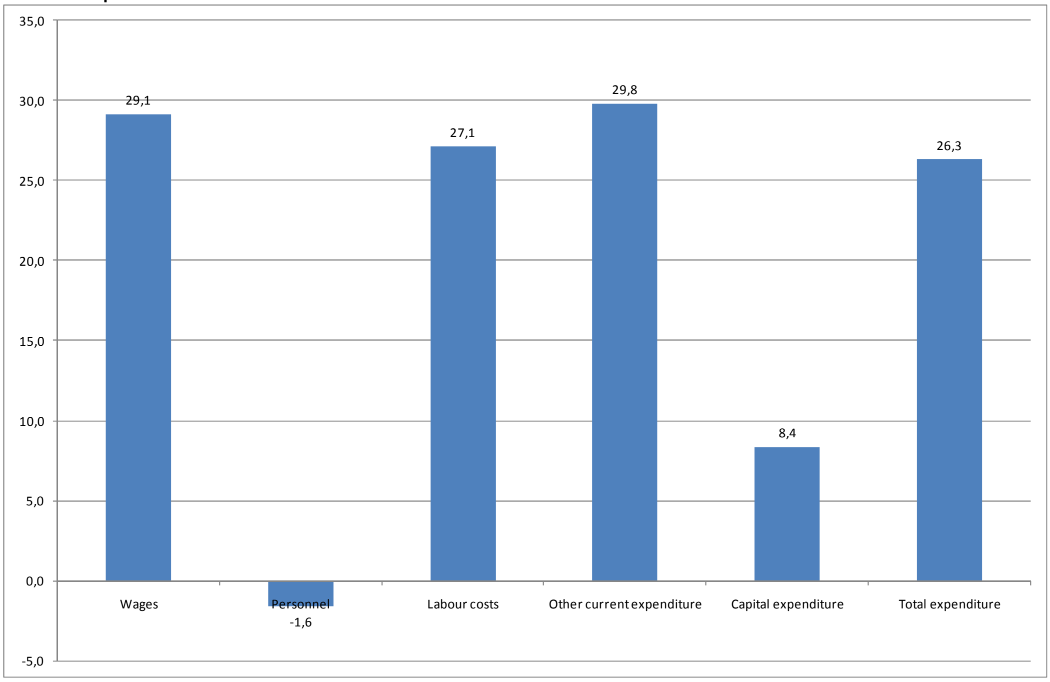
Source: OECD
Note: all categories are in PPS – 2000-prices, expect personnel: (Full-Time-Equivalents)
Due to mergers of a number of R&D organisations in the government sector with universities the last 10 years the statistics for Denmark show a peculiar pattern, which may mislead the reader.

3.1.4 A closer look at the business sector

This section takes a closer look at the business sector. In 2005, the business sector accounted for two third of total research expenditure among the countries included in the dataset. Compared to the increase in total R&D expenditure for all sectors, the increase in the business sector (BERD) was higher.

Figure 10 shows an increase in average research wage of about 30 per cent between 1997 and 2005. Concurrently, the number of research man-years in the business sector has been slightly reduced.

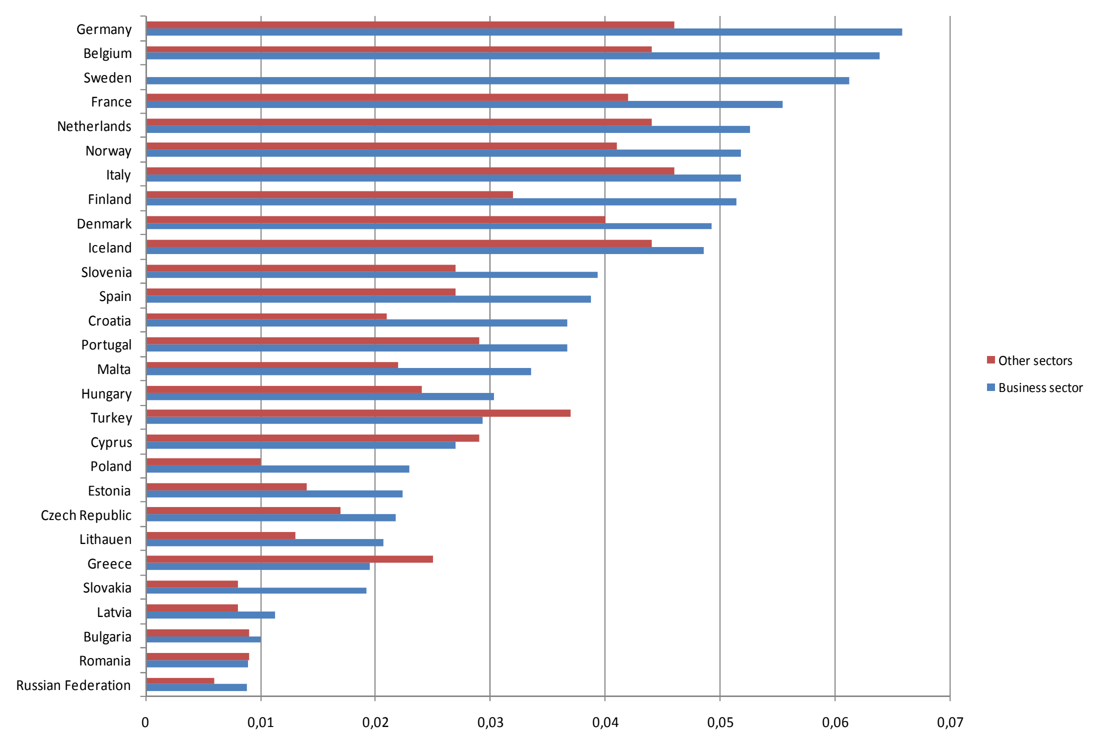
Figure 10: Growth in cost components, Business sector, 1997 and 2005, changes in per cent over the period.



Note: all categories are in PPS – 2000-prices, expect personnel: (Full-Time-Equivalents)
Source: Eurostat

Figure 11 reveals that the average wage level in the business sector was considerably higher in the business sector compared to the other R&D performing sectors (government and higher education combined) in nearly all countries. Such significant wage differences between R&D performing sectors within countries may in the long run lead to incentives for a gradual outsourcing of R&D from the business sector to domestic – and probably also foreign – higher education institutions and other governmental research institutes.

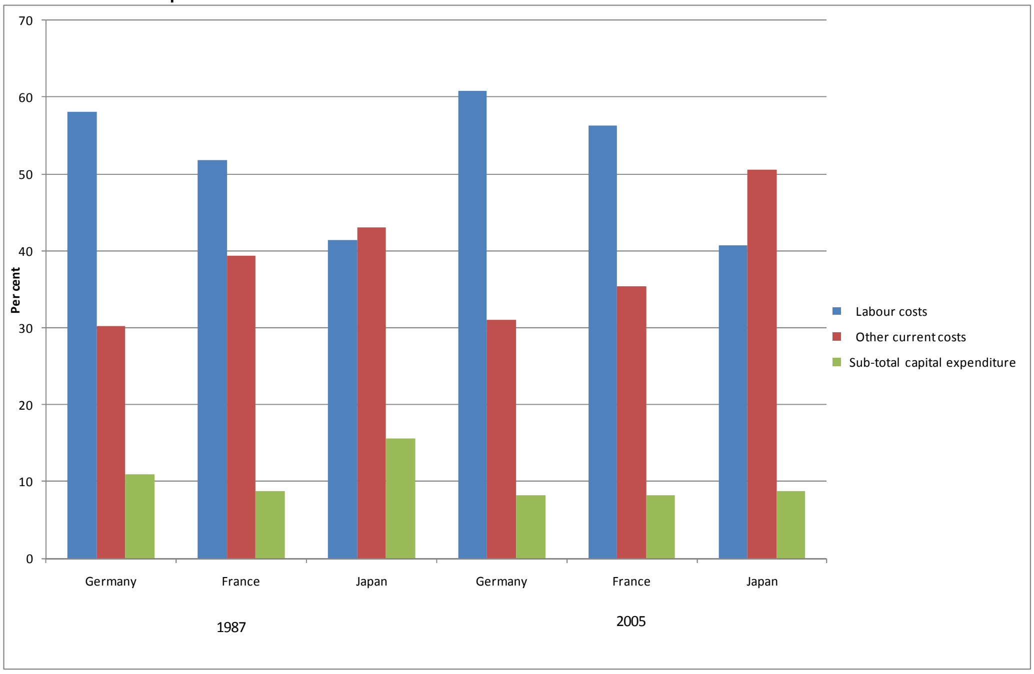
Figure 11: Average research wage levels in the business sector versus other R&D performing sectors in selected countries, 2005, million PPS at 2000-prices.



Source: Eurostat

In Figure 12 we have used OECD-data to look at changes in the R&D cost component distribution in the business sector for Germany, France and Japan, over a longer period of time, that is 1987 and 2005. The cost component "sub-total capital expenditure" has diminished most significantly for Japan. However, this cost-component is relatively insignificant, and all in all, the cost distribution has remained fairly stable over the time. In Germany and France, the share of R&D labour costs is clearly larger than in Japan, and this difference has actually increased from 1987 to 2005.

Figure 12: Distribution on cost components in 1987 and 2005, Business sector, Germany, France and Japan.



Source: OECD

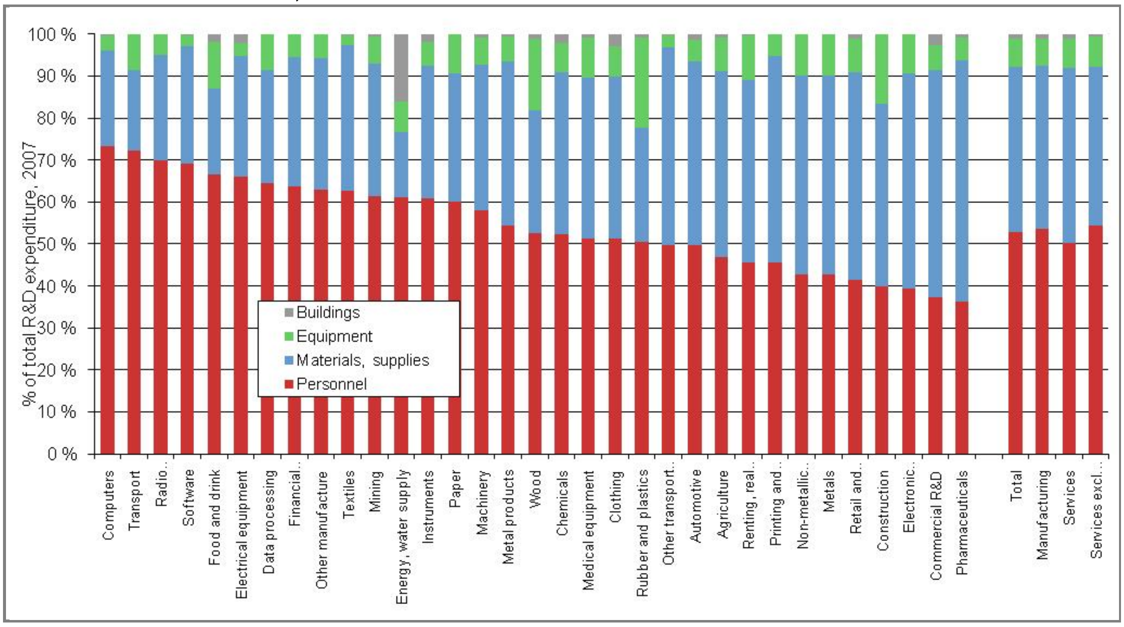
3.1.5 R&D cost components in different industry sectors

There are large differences between industry sectors with respect to how intensively businesses invest in R&D and one could imagine that at least within the high-tech sectors (pharmaceuticals, aeronautics, ICT, etc.) there may be pressures on domestic wages for researchers due to fierce international competition for talents and researchers in these research areas. In fact, we know little about how domestic versus international demand for researchers in different research fields and in different R&D performing sectors influence the formation of researchers' wages. Increased researcher mobility across countries suggests that the international competitions for researchers has increased and that this must have had an effect on wages and probably on other R&D cost components, for example, increased activity in conferences, research visits, research related travels, etc.

Furthermore, we know from the innovation literature that the style of R&D and innovation activities varies among economic sectors (e.g. Malerba 2004), a fact that may create differences in the volume and cost type composition of R&D expenditures among economic sectors.

For example, in Figure 13 the relative composition of the components of R&D expenses in the various economic sectors in Austria is depicted. The figure reveals relatively large variations even between the R&D-intensive sectors such as computers, radio communications, software, electronic components and pharmaceuticals. Based on data from Austria one should thus expect that in countries with a large pharmaceutical sector increases in current expenditures will in general contribute more to cost increases than increases in wages. Yet, as the figures show, this is not necessarily so.

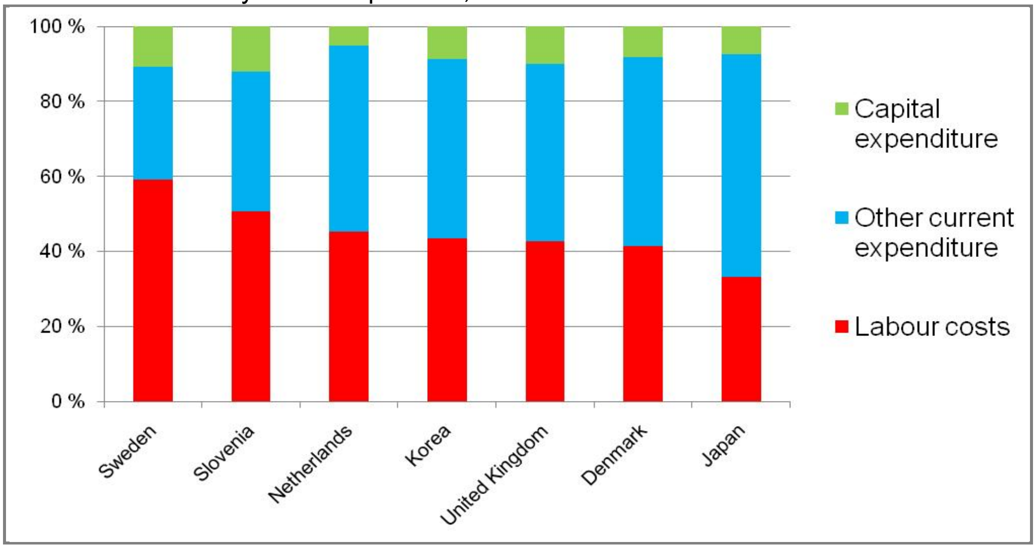
Figure 13: Composition of the cost of R&D in different sectors of economic activity in the Austrian business sector, 2007.



Source: Statistik Austria

Figure 14 suggest that there can be large variations in the R&D cost structure among countries even within the same type of industry (pharmaceuticals). Similar country differences are also found in software R&D, albeit not to the same degree. Such variations can probably be explained by variations in type of R&D performed, for example, differences in the mix of basic research and clinical testing.

Figure 14: Shares of total R&D expenditure in pharmaceutical sector (business sector) in selected countries by cost components, 2005.



Source: Eurostat

3.1.6 Conclusions

Based on publicly available statistical data some first conclusions can be drawn:

First, considering the entire sample of countries as one group we observe that labour costs and real wages in research increased significantly between 1997 and 2005. Figure 2 indicates that an increase in the volume of total R&D expenditures of 33 per cent between 1997 and 2005 resulted in an increase of research wage rates of 25 per cent and a much smaller increase of the volume of R&D employment (5 per cent). Thus we may conclude that increases of public and private funding of R&D in 1997-2005 resulted in global increases of wages in research probably because researchers is a scarce resource and the national education and research systems does not produce as many researchers as there is demand for.

Second, other current costs increased more than the labour costs and more than the total R&D expenditures. Furthermore, the share of other current costs by total R&D expenditures varies considerably between countries and between R&D performing sectors.

Third, standard economic theory states that differences of general wage levels between countries are associated with differences of labour productivity levels, i.e. higher labour productivity results in higher levels of wages.[10] Into a certain extent, wage levels in research seem to depend on the average level of wages in a given country. But differences in wage levels in research between countries do not necessarily imply that an R&D man-year in a low cost country is less productive than an R&D man-year in a high cost country. If the differences of research labour productivity are small between countries, then low-cost countries do have a comparative advantage compared to high cost countries.

On the other hand, the growth rates of average wages for R&D personnel vary a lot between countries indicating a 'catching up' process narrowing wage differentials. Thus, we expect to find that differences of average wage of researchers between countries are becoming significantly smaller compared to differences of general wage level differentials. This catching up process is probably fuelled by increases in public (and private) R&D funding.

Fourth, we expect that increased researcher mobility should normally lead to a convergence of research wage levels between countries. Large wage differentials between countries (and between R&D performing sectors) on the other hand, constitute a strong incentive for attractive and productive mobile researchers to leave low wage level countries and find researcher positions in countries with high- level wages. This type of researcher mobility would normally tend to equalize research wage differentials between countries.

Finally, data gaps are found all around countries and sectors, but despite this poor coverage of countries (especially the BRIC countries, but also many EU15 countries) and industries it seems reasonably clear that there are wide variations between countries and sectors with regard to the cost structure of R&D.

3.2 Studies on the price development of research costs

One direction in which cost of research is determined is a research strand which focuses on price development of various cost components of R&D. In Dougherty et al. (2003) and McGuckin et al. (2006) this research strand is briefly summarized and the basic message is that though it is possible to determine various cost components, differences in accounting

[10] See also the following chapter 3.2 were arguments for the development of productivity by Baumol are presented.

procedures, differences in R&D institutions and connection with universities and other research institutions make it difficult to compare R&D prices between countries. As suggested by Dougherty et al. (2003) one could however use price developments as a first proxy and try to refine these data by having interviews in the industries.

Table 1: R&D expenditure shares, total manufacturing, 1997 (in %).

R&D input category	France	Germany	Japan	Nether-lands	UK	US
Labour compensation	52.8%	61.7%	42.7%	52.1%	37%	46.5%
Materials and Supplies	16.9%	13.9%	20.3%	14.7%	26.1%	15.8%
Other current costs	23.2%	17.5%	27.3%	23.7%	24.8%	29.3%
Capital expenditures	7.1%	6.9%	9.7%	9.5%	12.1%	8.4%
Total R&D	100%	100%	100%	100%	100%	100%

Source: McGuckin et al. (2006)

The basics of the applied methodology are relative straightforward. The costs of R&D are disentangled into various expenditure categories such as labour, materials, capital costs and other current costs.[11] For each category the weight in total costs is determined and the price per unit of that particular input. This results in a comparison of prices per unit of input between various countries and the development of the shares in total costs of these categories. Table 1 shows the various expenditures shares in 6 OECD countries at an aggregate level in 1997. A similar table can be computed at a sectoral level but is not presented here. Note that the variation can be considerable. The share of capital expenditures for instance is almost twice as high in the UK as compared to Germany whereas the labour share is very high in Germany as compared to the other countries presented in the table.[12]

The prices per cost category can be computed relative to a base country. In this example the US is taken as base. Prices are computed in two steps. In the first step the price per unit of input is determined relative to a base country. For instance, the hourly wage cost of a researcher in the UK, expressed in British pounds, can be compared to the hourly wage cost of a researcher in the US, expressed in US Dollars. Applied to all expenditure categories this methodology results in a purchasing power parity comparison of all cost components. In a second step all monetary units can be expressed in one common currency using the exchange rates at that date. Table 2 shows the aggregate results where the R&D price levels are defined as the purchasing power parity divided by the exchange rate of the country's currency relative to the US dollar.

This table shows that e.g. one hour of R&D labour is in the UK 59% of the costs of one hour of R&D labour in the US, both measured in US Dollars. The general picture that emerges from this table is that the prices of R&D *labour* inputs in Europe are below the price of R&D labour in the US whereas prices of non-labour inputs are overall higher in Europe. Note that other current costs (e.g. overhead costs) fluctuate considerable between countries.

11 In an (more) ideal situation one would like to breakdown labour costs in various categories like scientists, technicians and support (cf. OECD, 1979).

12 Of course the columns add up to 100% so that the shares are correlated.

Table 2: R&D input price levels expressed in US dollars (cost relative to US) total manufacturing, 1997.

Input category	France	Germany	Japan	Nether-lands	UK	US
Labour compensation	0.85	0.97	0.94	0.77	0.59	1.00
Materials and Supplies	1.18	1.30	1.01	1.17	1.49	1.00
Other current costs	1.02	1.33	1.61	0.95	1.07	1.00
Capital expenditures	1.09	1.19	1.03	1.18	1.05	1.00

Source: McGuckin et al. (2006), Tables B6, B7, A2A, recalculated in US Dollar

Combining the information from Table 1 and Table 2 reveals comparable price levels of R&D between countries. This again can be done for the aggregate economies but also per sector. To show some sectoral results, Table 3 displays R&D price levels for pharmaceuticals and office, accounting and computing machinery in 1997. This table shows that R&D price levels for total manufacturing are high in Germany and Japan and low in the Netherlands and the UK but that this is not (always) the case for individual sectors. Price levels for R&D in office, accounting and computing machinery in Germany is for instance comparable to France and lower than Japan and the US.

Table 3: Price levels for R&D PPP in US Dollars, some sectors and aggregate manufacturing, 1997.

	France	Germany	Japan	Nether-lands	UK	US
Pharmaceuticals	0.92	1.03	1.27	0.81	0.88	1.00
Office, accounting & computing machinery	0.83	0.85	1.13	0.64	0.59	1.00
Total manufacturing	0.97	1.11	1.14	0.90	0.88	1.00

Source: McGuckin et al. (2006), B8, recalculated in US Dollars

To show price developments Table 4 includes the same figures for 1987. Remarkable is that R&D price levels in France, Germany and the Netherlands where relative higher in 1987 as compared to 1997. R&D prices in the UK are low in both years.

Table 4: Price levels for R&D PPP in US dollars, some sectors and aggregate manufacturing, 1987.

	France	Germany	Japan	Nether-lands	UK	US
Pharmaceuticals[13]	1.12	1.20	1.16	1.07	0.83	1.00
Office, accounting & computing machinery	1.18	1.11	1.00	1.07	0.85	1.00
Total manufacturing	1.08	1.15	0.98	1.06	0.78	1.00

Source: McGuckin et al. (2006), B18, recalculated in US Dollars

Finally, Table 5 shows the percentage changes of price of R&D between 1987 and 1997. R&D in France, Germany and the Netherlands has become cheaper whereas R&D in the UK has become more costly, but the latter is still low relative to the other countries. Note also that sectoral differences are considerable. Pharmaceutical R&D in the UK has become more costly whereas it decreased substantial in Office, accounting and computing machinery industry.

Table 5: Changes in price levels for R&D PPP, some sectors and aggregate manufacturing, 1987-1997 (in %).

	France	Germany	Japan	Nether-lands	UK	US
Pharmaceuticals	-18.0%	-14.2%	9.4%	-23.7%	6.1%	0.0%
Office, accounting & computing machinery	-29.4%	-23.8%	12.8%	-39.6%	-30.6%	0.0%
Total manufacturing	-10.5%	-4.2%	17.0%	-14.4%	12.7%	0.0%

Source: own calculation.

Though the tables as presented here may suggest otherwise, these data are not to be taken without caution. Especially other current costs and capital expenditures are (very) difficult to measure and in many cases some simplifying assumptions are made. This holds true for the shares in total R&D expenditures as well as for the individual price levels. A sectoral differentiation is in some cases not possible such that price developments for cost of capital and for other current costs are taken equal for all sectors of industry. This holds true for the shares in total R&D expenditures as well as for the individual price levels. For these reasons, McGuckin et al. (2006) perform interviews with representatives of high-tech firms in pharmaceuticals, computers, telecommunication equipment and automobiles. One of the reasons for such interview based additional research is to reveal legal or more broadly institutional differences. This is in particular important since various authors (among which OECD (1979), Heston and Summers (1996)) point at differences in accounting methods, difference in quality of inputs and differences in the research process itself, including spillover effects.

Quality of input factors is another important aspect and differences in educational systems, in the quality of education etcetera should be taken into account. Accounting for differences in

[13] Note that pharmaceuticals is defined as ISIC Rev 3: 24.4 in 1997 and as drugs and medicines, ISIC Rev 2: 3522 in 1987. Also Office, accounting and computing machinery uses slightly different classifications between 1987 (ISIC Rev2) and 1997 (ISIC Rev 3).

quality of labour can be done, at least in principle, by using official data, see for instance the work of Jorgenson (2001) in the area of ICT productivity and how to correct for labour quality based on years of education. Differences in quality of other input factors are more difficult to measure, however. Finally, the environment in which the research is conducted is highly important. This includes the location of similar knowledge based firms in an area, allowing for important spillovers, as well as the legal and institutional environment.

Studies on pure price effects start from straightforward accounting principles. Obviously an important assumption in this methodology is that the quality of the research process is comparable or constant and that the research environment is comparable. This refers to specific local institutions and the general `research` environment. Certainly at an industry level, it is sometimes difficult to determine prices of inputs such as capital costs. Moreover differences in accounting principles, differences in institutional settings, in collaborations with universities and other (semi-public) research institutions and differences in the way costs of these collaborations are accounted for bias these findings. All studies indicate that obtaining information through e.g. interviews or surveys is needed to get a better picture of those factors.

To conclude, comparable price levels of R&D can be calculated based on several input factors in the R&D process. This methodology determines the most important cost categories of the research process and measures price levels and price developments of each input. From this, an index on the cost of research can be determined and countries and or sectors can be compared. This can be done at the aggregate level but also at a sectoral level, in McGuckin et al. (2006) limited to manufacturing, however, and for some expenditure components a sectoral differentiation is not possible. The differences in accounting principles but also other differences including quality aspects of inputs factors, spillovers from universities and other public and semi-public institutions and the way these are included in the cost of R&D demonstrate a clear need for additional geographical, institutional and sectoral specific research. Moreover, the data as presented here do not reveal changes in the overall R&D process and the nature and impact of inventions and innovations. Research and development on path-breaking general purpose technologies cannot as such be compared to small innovations. In that sense, the statistics of prices or costs of R&D do not provide insights and other input and output measures of the research process are needed.

With respect to the development of wage costs we also want to refer **Baumol's work on cost disease**. Baumol's cost disease considers the fact that some sectors of the economy are burdened by a relentless rise in labour costs because they tend not to benefit from increased efficiency, i.e. are the result of a productivity lag. Productivity may increase over time due to an increased capital per worker, improved technology, increased labour skill, better management and economies of scale as output rises (Heilbrun 2005). These facts, however, mostly refer to industries using a lot of machinery and equipment, i.e. manufacturing industries.

Analyzing this discrepancy, some general assumptions need to be made. The underlying assumption of Baumol's cost disease is the differentiation between two groups of economic activity: this is at first technologically progressive activities rising the output per man hour, and second activities which permit only sporadic increases in productivity, while the assignment of any activity to one group or the other is determined by the activity's technological structure (Baumol 1967). The differentiation of the above mentioned activities is based on labour in the activity, being labour an instrument to attain the final product, like in the manufacturing sectors or being labour the final product itself, like in the service sectors. Furthermore, Baumol, although admitting that there might be disparities in wage levels between the two sectors, which in the long run are converging, assumes that wages in both sectors together increase and decrease respectively. The final assumption of Baumol to be mentioned here is that *"money wages will rise as rapidly as output per man hour in the sector where productivity is increasing"* (Baumol 1967, p. 417).

Baumol shows that *"if productivity per man hour rises cumulatively in one sector relative to its rate of growth elsewhere in the economy, while wages rise commensurately in all areas, then relative costs in the non-progressive sectors must inevitably rise, and these costs will rise cumulatively and without limit"* (Baumol 1967, p. 419). Thus, real costs in the non-progressive sector are likely to be increasing; the services that have been infected by the cost disease, are those, *"in which the human touch is crucial, and are thus resistant to labour productivity growth"* (Baumol, 1993, p. 19). Therefore, labour content of these services can hardly be reduced; the quality of the output is inevitably correlated with the amount of human labour devoted to achieving the output, i.e. the service.

If the findings from Baumol and Bowen (Baumol and Bowen, 1966) are related to research and development – which is to be assigned to the services sector – research and development is resistant to labour productivity growth, as this industry requires a large amount of 'human touch'. Thus, skilled labour in the non-progressive sector, gets more expensive due to increased relative costs. This, in consequence, may be one possible explanation for the growing share of precarious working situations in the field of research and development, especially of recent graduates (Schneeberger and Petanovitsch 2010). We cannot, however, conclude that this inevitably is a reason for firms to internationalize its research and development activities. The internationalization of research sites is normally based on a firm's long-term strategies; these services will equally be infected by the cost disease in the potential host country, although a discrepancy in wage levels might still be an assignable cause.

Nonetheless, it has to be mentioned here, that Baumol modeling the unbalanced growth ignores nonwage costs. This assumption, however, might hold, as labour costs account for a large part in both manufacturing and service industries. Still, there is one fact that has to be taken into consideration here: Baumol's economic dilemma focuses on measured pecuniary costs, but does not take into account value added in productive processes, i.e. excludes quality improvements (Cowen 1996).

3.3 The development of research costs: Findings from the empirical study

3.3.1 Companies

3.3.1.1 Development of cost composition

We start our analysis by presenting the current **cost composition** of the surveyed companies. As noted above, large firms are increasingly performing R&D in many different locations, not only in Europe but also in overseas. When asking the companies about the composition of their research costs we therefore asked them to distinguish between the 'world main region' and the so called 'most dynamic region'. **In the survey it is stated that regions with the highest expected economic growth or the best opportunities for the company are comprised under 'the most dynamic region'.**

Our survey shows that **wage costs are the major component of research costs**, followed by capital costs and purchased costs.

Cost shares in 'main world region' and the 'most dynamic region' are not very different regarding the R&D wage costs as exhibited in Table 6 and Figure 15, despite the much lower wages in e.g. dynamic BRIC economies. In contrast, our analysis of the statistical data above (see Figure 5) has revealed, that within EU27 the share of wages in total R&D costs varies from 62% in Malta to 35% in Latvia. Therefore 50.03% seems to be rather low while 47.26% for most dynamic regions seems to be rather high. However, the survey data comprises micro data and it might be possible that the domestic wage levels and those abroad differ less than the averages reported by national statistics. The results revealed from our survey rely on the firms' own assessments which countries are to be assigned the most dynamic regions (and might therefore be different for each firm), though, we cannot trace back results to one particular country.

The rather high share of wages in 'most dynamic regions' might also be caused by a low share of local (indigenous) R&D workers in total R&D workers, due to high turnover rates of local R&D employees. It may also be caused by the lack of loyalty to the foreign company as found in the case studies on China conducted by e.g. Gassman and Han (2004).

Apparently, the market for highly skilled international researchers has become a global market with globally comparable wages.

In contrast, the cost share of purchased R&D appears to be much lower in 'dynamic regions' compared with the main location, which could indicate that R&D services are still a less important component of R&D expenditure in the 'dynamic regions'. It also suggests that in the European home-base, companies sub-contract more R&D to external parties. Companies may not have found suitable partners in the most dynamic regions yet, but in terms of Open Innovation and R&D networking the main world regions still seems to have a comparative advantage over the most dynamic regions.

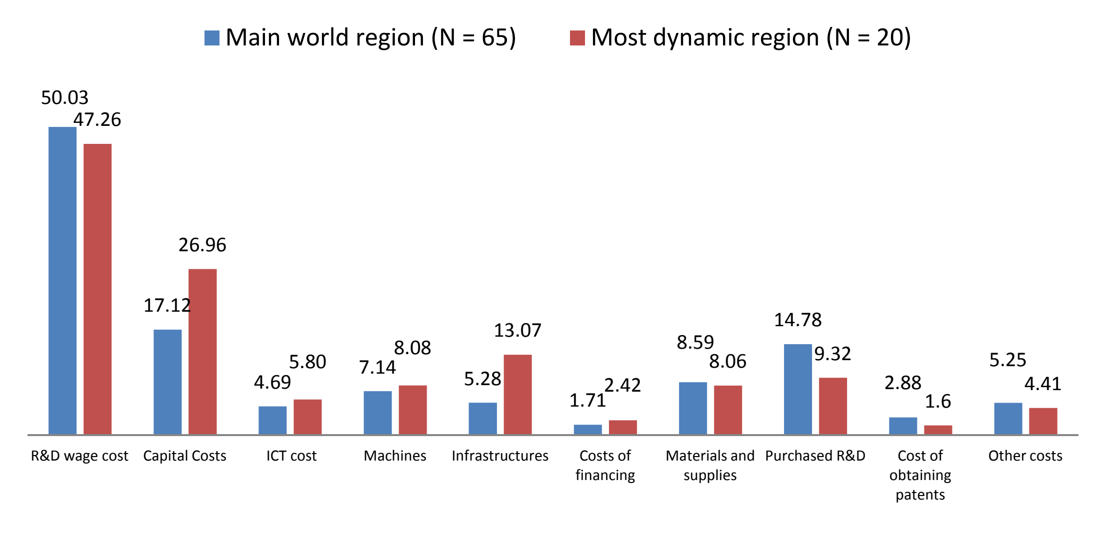
The costs of infrastructures and financing are much higher in the dynamic regions. This high share of capital investments, especially in R&D infrastructures accords with the catching-up developments in the most dynamic regions.

Table 6: Current cost composition of R&D in companied (in %).

Cost shares (Companies)	**main world region** (N = 65)	**most dynamic region** (N = 20)
R&D wage cost	50.03	47.26
Capital Costs	17.12	26.96
ICT cost	4.69	5.80
Machines etc.	7.14	8.08
Infrastructures etc.	5.28	13.07
Costs of financing	1.71	2.42
Materials and supplies	8.59	8.06
Purchased R&D	14.78	9.32
Cost of obtaining patents	2.88	1.60
Other costs	5.25	4.41
SUM (%)	100	100

Source: EU Survey on Cost of Research (2011)

Figure 15: Current cost composition of R&D in companies (in %).

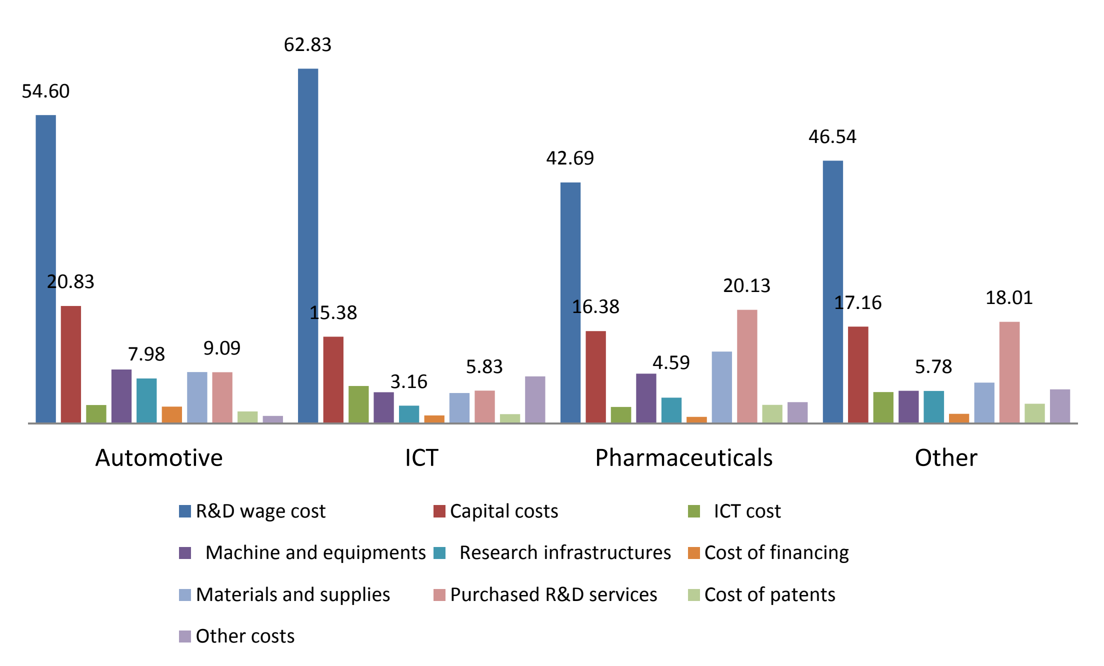


Source: EU Survey on Cost of Research (2011)

The **share of wages** - in the main world region - varies over the sectors (see Figure 6): as expected ICT exhibits the highest share of wages in R&D cost (63%) while pharmacy and chemical exhibits the lowest (43%), the other sectors have an average wage share of 47%. Capital costs are the highest in the automotive sector (21%), ICT the lowest with 15%. Purchased R&D is the highest in pharmaceutical (20%) and other industries, ‘Other costs’ are sometimes specified by respondents: The categories mentioned are travel (cost share 10-12%), other service (share 27%), overheads (16%) and university collaboration (6%).

These results are in line with findings from Austria (Figure 13), and may therefore be further in line with findings from other western European countries, which mostly corresponds to results from the “main world regions” (see also Figure 14): The share of wages is highest in Computers and Transport (over 70% of total R&D expenditure), while Construction, Electronics, Commercial R&D and Pharmaceuticals exhibits the lowest shares (below 40%). We can assume from Figure 13 that likewise findings regarding capital costs, purchased R&D and other costs point to similar tendencies, though no direct comparisons can be made, as type of costs are not defined identically.

Figure 16: Current cost composition of R&D in companies by sector (in %).



Source: EU Survey on Cost of Research (2011)

Table 7: Current cost composition of R&D in EU-companies: groups of EU countries (in %).

	EU-Cont (N = 32)		EU-Nord (N = 35)		EU-Sud (N = 22)	
	Main world region	**Most dynamic region**	**Main world region**	**Most dynamic region**	**Main world region**	**Most dynamic region**
R&D wage cost	51.12	48.39	48.89	46.81	48.68	45.15
Capital costs	18.79	25.96	15.82	27.34	18.99	29.61
ICT	4.28	5.91	4.68	5.85	6.22	6.70
Machine and equipments	8.62	8.19	6.88	8.30	6.71	8.78
Research infrastructures	5.89	11.87	4.25	13.20	6.06	14.13
Cost of financing	2.66	2.30	1.11	2.31	1.30	2.83
Materials and supplies	9.33	7.55	7.57	8.28	7.50	8.78
Purchased R&D services	11.15	9.99	17.86	9.26	16.01	8.74
Cost of obtaining patents	2.50	1.64	3.61	1.52	2.64	1.66
Other costs	5.49	4.18	5.01	4.49	5.23	3.25
SUM	100	100	100	100	100	100

EU-Nord = DK, FI, NL, SE, UK
EU-Sud = ES, FR, IT
EU-Cont = DE, AT, P, BE
Source: EU Survey on Cost of Research (2011)

Table 7 shows the current cost composition of R&D of the EU-Scoreboard firms (= 89 firms) by group of EU countries. The differences among continental, northern and southern are not very strong. Only for purchased R&D services emerges some differences in the most dynamic region, with northern and southern EU countries more dependent on this item (18% and 16% respectively), compared with continental EU countries (11%). Generally speaking, for all groups of countries capital costs are higher in the most dynamic region, and in particular with regard to research infrastructures (compared to the main world region). Also the Purchased R&D is generally less important in the dynamic region than in the main one.

With respect to the size there are not any significant differences (not disclosed here).

3.3.1.2 Changes due to price and volume

In the COST survey we have asked for the **development of the main research cost categories in the past and the expectation about the future development**. Thereby we examine whether this is a price or volume effect (companies had to assess the main driver of change) and therefore constructed a price/volume index which varies between 1 (= pure price effect), and 2 (= pure volume effect), so that a value higher than 1.5 means an increase due mainly to volume effect.

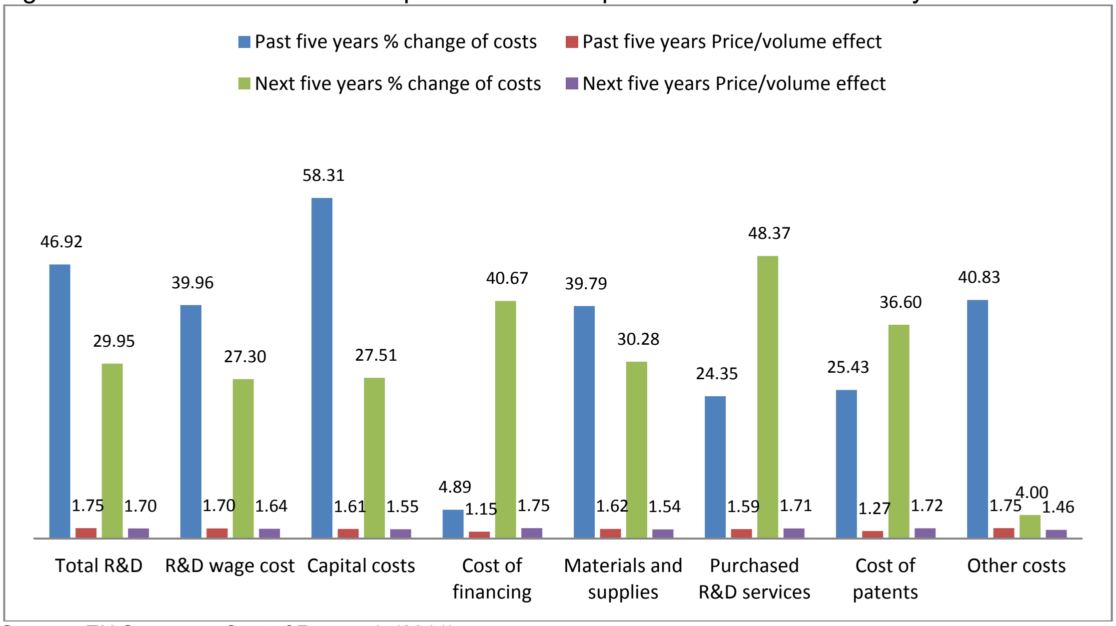
The **cumulative cost developments** over the past five years show a high increase of total R&D costs of 47%, which as Figure 17 shows, is mainly a volume effect.

The **main component of the R&D cost increase is represented by capital costs**, whose percentage of change in the last five years was 58% still due to volume effect (1.6). The only two components' cost increase due to price effect are financing (1.15) and patents (1.27). Anyway, the growth in cost of financing in the past five years was only 4.9%.

These findings are somewhat at odds with results obtained by the statistical analysis of the business sector. Capital costs are the cost component of R&D expenditure, which grew least in the business sector (see Figure 6) over 1997 to 2005. In contrast, "other current expenditure" has grown the most (37 per cent) between 1997 and 2005 in a number of OECD countries. The component labour costs has increased significantly as well (31 per cent) whereas most of this increase is associated with increases of wages (25 per cent) and not of the number of personnel (FTEs). The latter increased only with 5 per cent from 1997 to 2005.

A total different picture emerges when considering the **cost development over the next five years**: the increase of the cost of total R&D is 30%; much higher than this average are two components: the cost of financing (increasing of 41%, mainly due to volume effect), and the cost of purchased R&D services (48.4%) again driven by a volume effect. This result predicts a more 'open' R&D cost structure in the future, where companies become more dependent on external sources, both in terms of R&D outsourcing and external financing, while the more 'closed', past structure was mainly characterized by capital investment in process innovation. The simultaneous expected change in capital costs and purchased R&D services could indicate that companies will make more use of external research infrastructures, and no longer opt to own it all themselves.

Figure 17: Cumulative cost developments over the past five and the next five years.



Source: EU Survey on Cost of Research (2011)

Table 8 and Figure 18 (graphical presentation) shows the cost development and price/volume effect by sector. In the past five years, the total R&D costs have increased more than 50% for Pharmaceuticals and Other sectors, while less than 50% for Automotive (37%) and ICT (37%). In the future the sectors expecting the greatest growth of R&D costs are Pharmaceuticals and Other sectors (30%), followed by ICT (29%) and Automotive (26%). The cost component that increased more in the past for Automotive was R&D wages (+41%), for ICT R&D financing and wages (both 30%), for Pharmaceuticals materials and supplies (62%), and for Other sectors capital costs (96%). In the future these factors become: for Automotive the cost of financing (+26%), for ICT the purchased R&D services (103%), for Pharmaceuticals the cost of financing (65%), and for Other sectors capital costs (46%). Observe the negative sign (cost decrease) for past cost of financing in Automotive (-57%) and for past purchased R&D services in ICT. Finally, generally speaking, the driving effect of these variations is the volume one, except some cases signalling, in any case, a quite low price effect (around 1.40).

Table 8: Cost Development and price/volume effect by sector.

Automotive (N = 15)	**Past five years**		**Next five years**	
	% Change of costs	**Price/volume effect**	**% Change of costs**	**Price/volume effect**
Total R&D	37.05	1.77	26.51	1.78
R&D wage cost	41.33	1.73	24.95	1.62
Capital costs	23.83	1.40	12.60	1.50
Cost of financing	-57.00	2.00	26.00	1.67
Materials and supplies	96.67	2.00	20.36	1.47
Purchased R&D services	15.33	1.38	16.22	1.62
Cost of patents	0.67	0.50	11.50	1.50
Other costs	11.67	1.67	no obs	no obs
ICT (N = 21)	**Past five years**		**Next five years**	

	% Change of costs	Price/volume effect	% Change of costs	Price/volume effect
Total R&D	37.63	1.64	28.87	1.63
R&D wage cost	30.10	1.67	26.60	1.50
Capital costs	23.00	1.40	9.71	1.29
Cost of financing	30.00	2.00	40.40	1.60
Materials and supplies	0.40	1.40	24.25	1.57
Purchased R&D services	-10.40	1.60	103.00	2.00
Cost of patents	4.40	1.40	59.00	2.00
Other costs	49.50	2.00	0.20	1.50
Pharmaceuticals (N = 27)	**Past five years**		**Next five years**	
	% Change of costs	**Price/volume effect**	**% Change of costs**	**Price/volume effect**
Total R&D	51.00	1.73	30.45	1.55
R&D wage cost	42.66	1.83	30.30	1.78
Capital costs	49.37	1.71	22.14	1.63
Cost of financing	27.00	1.71	65.00	2.00
Materials and supplies	61.85	1.86	41.60	1.67
Purchased R&D services	34.25	1.75	53.57	1.71
Cost of patents	47.44	1.50	50.00	1.67
Other costs	49.71	1.57	1.90	1.00
Other (N = 40)	**Past five years**		**Next five years**	
	% Change of costs	**Price/volume effect**	**% Change of costs**	**Price/volume effect**
Total R&D	52.72	1.81	31.47	1.81
R&D wage cost	42.79	1.63	26.47	1.62
Capital costs	95.80	1.74	46.05	1.67
Cost of financing	0.00	0.00	29.90	1.70
Materials and supplies	24.25	1.44	29.47	1.47
Purchased R&D services	39.30	1.55	28.23	1.59
Cost of patents	30.90	1.33	25.20	1.70
Other costs	41.22	1.78	8.85	1.75

Source: EU Survey on Cost of Research (2011)

Figure 18: Cost Development and price/volume effect by sector.

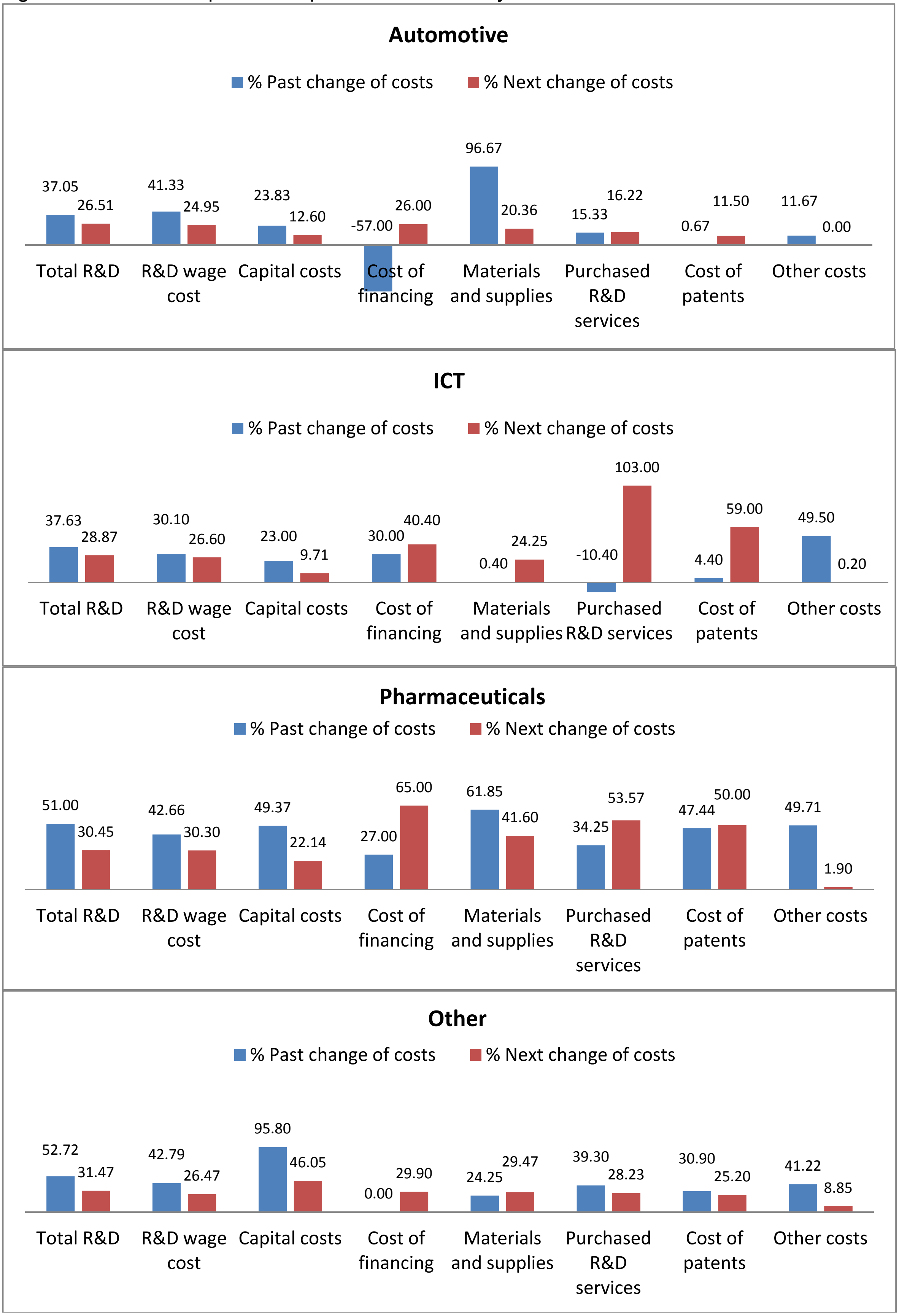


Table 9 sets out the cost development and price/volume effect by size. Small firms have the higher overall increase of past total R&D costs (51%), followed by large (46%) and medium (42%) companies[14]. For all small, medium and large firms, capital costs is the component that increased more in the past (57%, 46% and 71%, respectively), while for the future it will be purchased R&D services (49%, 31% and 63, respectively). Thus, large firms seem to have had and to expect larger costs on both components. Observe, also, the high expected increase in the cost of financing expressed by large companies (45%). Finally, no great differences emerge in the price/volume index, where the volume effect dominates.

Table 9: Cost Development and price/volume effect by size.

Small (N = 42)	**Past five years**		**Next five years**	
	% change of costs	**Price/volume effect**	**% change of costs**	**Price/volume effect**
Total R&D	51.00	1.80	30.62	1.72
R&D wage cost	43.28	1.79	29.89	1.67
Capital costs	57.26	1.56	23.29	1.58
Cost of financing	4.67	1.12	42.73	1.78
Materials and supplies	43.09	1.63	35.39	1.56
Purchased R&D services	26.66	1.58	49.15	1.73
Cost of patents	24.11	1.28	37.54	1.71
Other costs	41.06	1.70	2.86	1.42
Medium (N = 30)	**Past five years**		**Next five years**	
	% change of costs	**Price/volume effect**	**% change of costs**	**Price/volume effect**
Total R&D	41.73	1.73	28.66	1.75
R&D wage cost	34.83	1.61	23.26	1.61
Capital costs	46.64	1.58	28.23	1.57
Cost of financing	-6.23	0.85	32.37	1.67
Materials and supplies	40.09	1.63	22.26	1.47
Purchased R&D services	26.23	1.57	31.61	1.66
Cost of patents	23.48	1.17	25.41	1.69
Other costs	35.77	1.75	5.06	1.64
Large (N = 31)	**Past five years**		**Next five years**	
	% change of costs	**Price/volume effect**	**% change of costs**	**Price/volume effect**
Total R&D	46.43	1.69	30.31	1.62
R&D wage cost	40.43	1.68	27.69	1.61
Capital costs	71.01	1.72	32.52	1.50
Cost of financing	15.97	1.47	45.92	1.80
Materials and supplies	35.03	1.60	31.11	1.59

[14] In the survey, "small" firms are defined as those having less than 500 R&D employees (in FTE), "medium" as those having this value between 500 and 1,000, and finally "large" as those with more than 1,000 R&D employees.

Purchased R&D services	19.41	1.62	63.53	1.74
Cost of patents	29.12	1.35	46.15	1.78
Other costs	45.43	1.83	4.50	1.37

Source: EU Survey on Cost of Research (2011)

Table 10 shows the cost development and price/volume effect for EU and non-EU company ownership. Overall, the main effect in cost development will be driven by the volume effect (except for cost of financing and patenting). The main difference between EU and non-EU ownership of companies emerges in the percentage of costs' increase, with non-EU companies having higher cost increases both in past and next five years. For instance, the total R&D costs in non-EU companies in the past five years was 60% while it was 45% in companies from EU countries; R&D wage costs grew of 45% in non-EU and 39% in EU companies; capital costs increased of 104% in non-EU companies and 52% in EU companies. Interestingly, for companies of both EU and non-EU countries of ownership the cost item that increased more in the past was the capital cost (51% and 104%, respectively), while for the future it is the purchased R&D that is expected to grow most (47% and 54%, respectively).

Table 10: Cost Development and price/volume effect: EU versus Non-EU companies.

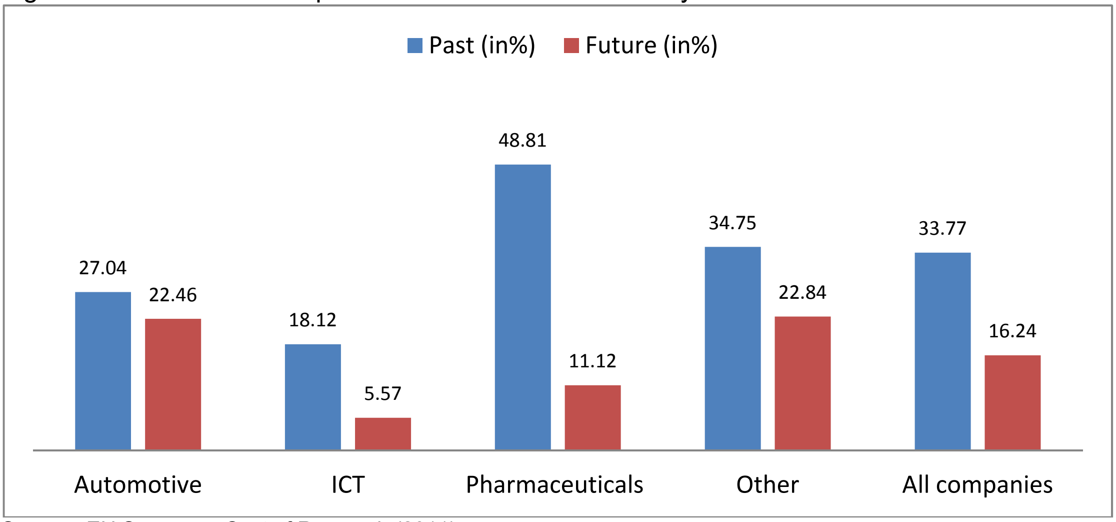
EU (N = 89)	**Past five years**		**Next five years**	
	% change of costs	**Price/volume effect**	**% change of costs**	**Price/volume effect**
Total R&D	44.85	1.74	28.89	1.71
R&D wage cost	39.21	1.69	26.65	1.63
Capital costs	51.05	1.61	24.60	1.56
Cost of financing	4.35	1.11	39.74	1.75
Materials and supplies	38.48	1.61	29.47	1.54
Purchased R&D services	22.58	1.58	47.47	1.70
Cost of patents	24.25	1.26	35.60	1.72
Other costs	40.67	1.74	3.46	1.46
Non-EU (N =14)	**Past five years**		**Next five years**	
	% change of costs	**Price/volume effect**	**% change of costs**	**Price/volume effect**
Total R&D	60.12	1.78	36.70	1.62
R&D wage cost	44.69	1.80	31.41	1.68
Capital costs	104.42	1.65	45.98	1.50
Cost of financing	8.36	1.37	46.63	1.78
Materials and supplies	48.15	1.69	35.40	1.58
Purchased R&D services	35.65	1.64	54.08	1.75
Cost of patents	32.96	1.32	42.91	1.75
Other costs	41.87	1.81	7.41	1.44

Source: EU Survey on Cost of Research (2011)

Besides the development of different cost categories we collected data about the number of **R&D employees** with the COST survey. The data on employment shows that the growth rate in the previous five years was 33.7% (table not disclosed here) while the expected growth rate for the next five years is 16.24% (this is cumulative growth over five years) thus slightly around 3% annually for the next five years.

Figure 19 discloses the growth of R&D personnel in past and future five years by sector. Pharmaceuticals shows the highest past growth rate (49%) followed by other sectors (35%), Automotive (27%) and ICT (18%). For the future, it is other sectors and automotive that declare the highest growth rate of R&D employment (22%) with Pharmaceuticals showing a 11% and ICT a 6% of growth. No sector expects to employ a higher number of research staff than in the past.

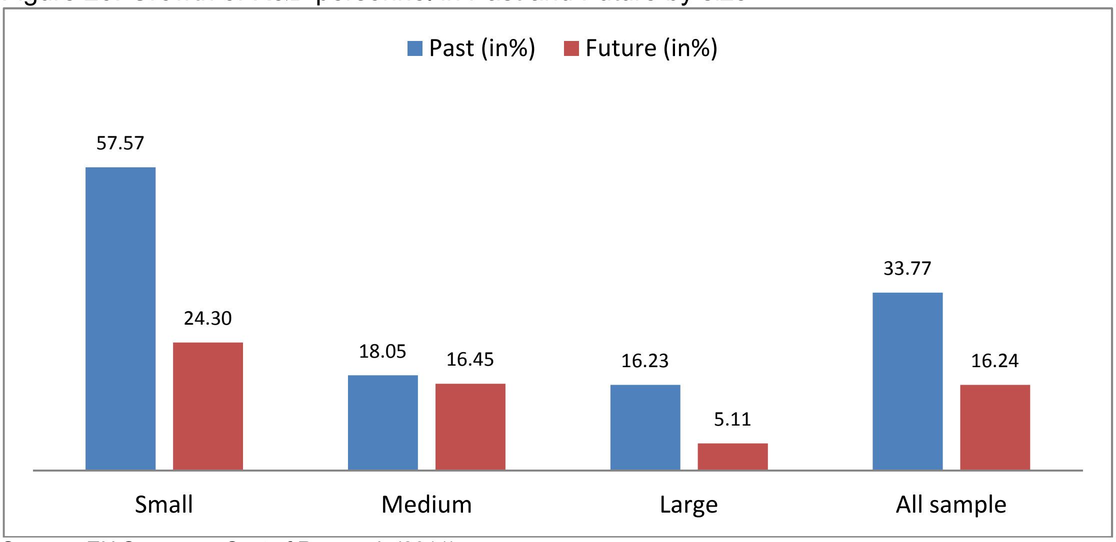
Figure 19: Growth of R&D personnel in Past and Future by sector.



Source: EU Survey on Cost of Research (2011)

Figure 20 depicts the growth of R&D personnel by size. In the past small firms exhibited the highest growth rate (57%) followed by medium (18%) and large (16%) companies. In the future, small firms remain those with the highest expected growth rate (24%), followed again by medium (16%) and large (5%) companies.

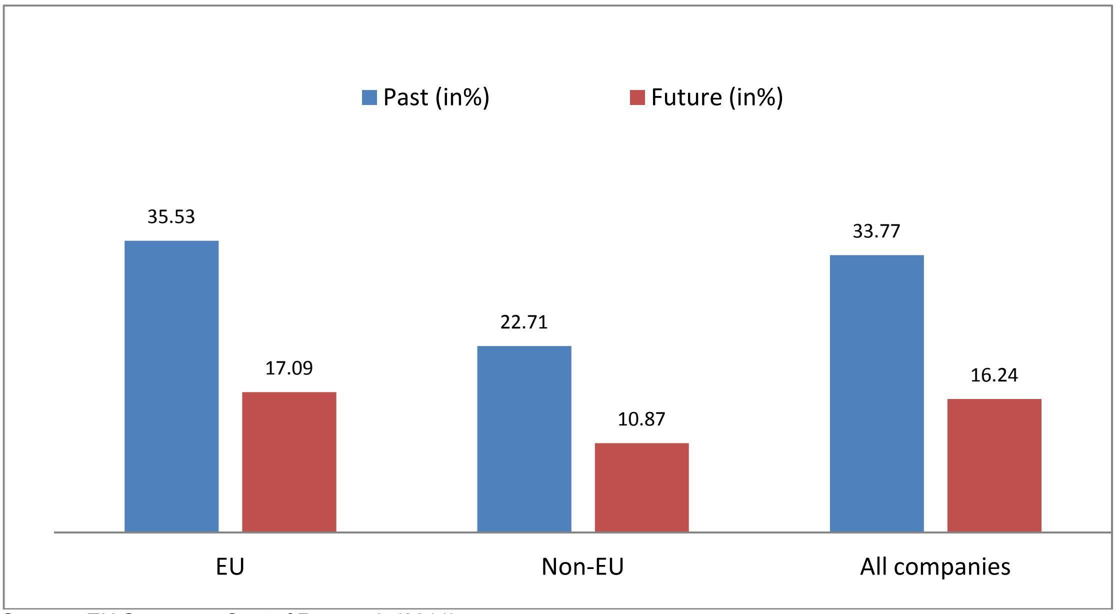
Figure 20: Growth of R&D personnel in Past and Future by size.



Source: EU Survey on Cost of Research (2011)

Figure 21, finally, shows that EU companies had in the past a growth of R&D personnel (65%) higher than non-EU companies (22%), and in the future this difference is expected to be stable, with EU companies declaring an increase of 17% and non-EU companies of 10%.

Figure 21: Growth of R&D personnel in Past and Future: Companies from EU versus Non-EU countries.



Source: EU Survey on Cost of Research (2011)

If we compare the growth in wage cost from Figure 17 with the growth in R&D employment, the cumulative past five years growth in R&D employment is 33.8% while for the cost share this growth is 28.1 % (taking into account only the growth due to volume effects).This difference may be due either to the existence of other factors, e.g. mostly R&D workers not counted as R&D employees, but hired on a temporary and/or contractual basis, or to a lacking accuracy in the data. Because employment data is easier to recollect for the respondent than cost developments, it is more likely that the volume of employment in R&D is correct in the companies surveyed. On the other hand the wage cost consists of three components: price (inflation), quality and a wage rate. Since the main effect of growth of wage costs is in the volume (see again Figure 17), it is likely that the main driver of the R&D employment cost increase is due to a better quality of R&D workers, based on more training than on a change in wage rate, thus ending up in the volume dimension of growth of labour costs.

Above we have also presented the development in researchers, technical staff and other supporting staff in R&D (see Figure 3). This data revealed a relatively strong reduction of “other supporting staff” in the past which may be a reflection of outsourcing of R&D activities and also a reason why “other current expenditure” have grown considerable at the same time. This and other reasons will be explored also in the next chapter.

In comparison, our analysis of statistical data (see Figure 10) has shown an increase in average research wage of about 30 per cent between 1997 and 2005. This analysis has also revealed (see Figure 11) that the average wage level in the business sector was considerably higher in the business sector compared to the other R&D performing sectors (government and higher education combined) in nearly all countries. Such significant wage differences between R&D performing sectors within countries may in the long run lead to incentives for a gradual outsourcing of R&D from the business sector to domestic – and probably also foreign

– higher education institutions and other governmental research institutes. However, as the case studies have shown it gets more and more difficult for PROs to attract very good scientists.

3.3.1.3 Development in different regions

Next we will examine in more detail where R&D activities are performed and to what extent the location patterns have changed. Indeed our survey shows that the **location of R&D in companies is changing**. The trend is increasingly out of EU15 and going elsewhere. Other EU27[15], China, India, Russia and other locations seems to become more attractive. Table 11 below depicts the results with regard to all companies (non EU and EU) while Table 12 separates between EU and non-EU firms.

The location of R&D activities financed by EU companies is gradually shifting from EU15 locations towards US & Canadian, Chinese, Indian, Russian, and other locations. The main R&D location of EU companies was, is and will remain EU15 (with over 74 percent) but the share located in EU15 is decreasing, while the share located in the US and Canada, other EU27, China, India, and Russia are on the increase. The main R&D location outside EU still is US & Canada, however it is clear that Other EU27, China, India, Russia and 'Other locations' are gaining ground according to the assessments of the (EU) respondents. In total the non-EU share in R&D performed and financed by EU companies will in the next five years more than double compared with 5 years ago. Respondents assessed that this non-EU share will reach 19% over five years, while it was 10% five years ago (see in Table 12, the EU columns).

Table 11: Location of R&D activities financed by companies (in %).

All Companies	**5 years ago** (N = 84)	**Present** (N =85)	**over 5 years** (N = 83)
EU15	78.36	74.85	66.77
Other EU27	2.34	3.14	4.48
Switzerland	0.38	0.48	0.60
Other European countries	1.46	1.43	1.74
US and Canada	7.16	9.08	9.67
Japan	5.12	4.99	5.21
China	0.45	1.20	2.70
India	1.57	1.95	3.27
Russia	0.15	0.14	0.42
Other countries	1.62	2.25	2.80
Compensating error[16]	*1.39*	*0.49*	*2.34*
SUM	100	100	100

Source: EU Survey on Cost of Research (2011).

Table 12 shows the same figures as Table 11, but this time by splitting them up into EU and Non-EU companies. As it is immediate to see, for both EU and Non-EU companies the share of R&D performed within the EU15 location sets out (from five years ago until the next five years) a clear-cut decreasing pattern. Moreover, while the composition of the other locations is rather uniform for Non-EU firms, EU companies show - over time - a general increase of the

[15] Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovak Republic and Slovenia.

[16] A "compensating error" has to be inserted in order to get a sum equal exactly to 100%. These errors depends on the existence of missing values replaced by industry averages. See the methodological Appendix.

R&D performed in all the remaining geographical areas (included EU27 and Other EU countries). This means that a “reallocation” of the R&D activity outside EU15 is taking place. Furthermore, as part of this reallocation is in favour of US, Canada and Japan (that is, comparable developed geographical areas), previous finding might signal a loss of competitiveness of EU15 in terms of companies’ R&D expected profitability.

Table 12: Location of R&D activities financed by EU and Non-EU companies (in %).

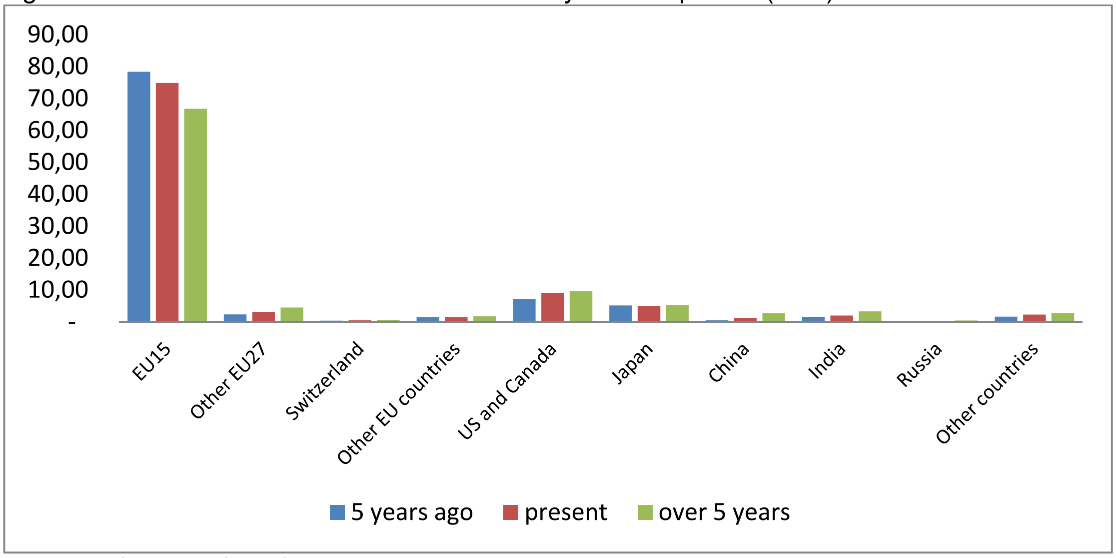
	EU			Non-EU		
	5 years ago (N = 75)	**Present** (N = 75)	**over 5 years** (N = 73)	**5 years ago** (N = 11)	**Present** (N = 9)	**over 5 years** (N = 10)
EU15	86.41	82.44	73.39	27.17	26.56	24.72
Other EU27	1.55	2.45	3.97	7.33	7.56	7.76
Switzerland	0.14	0.24	0.40	1.91	2.01	1.89
Other Eur. countr.	0.49	0.47	0.92	7.63	7.47	6.97
US and Canada	5.61	7.77	8.40	17.03	17.40	17.74
Japan	1.46	1.46	1.64	28.39	27.42	27.85
China	0.51	1.33	2.93	0.06	0.38	1.26
India	0.63	1.07	2.60	7.52	7.54	7.55
Russia	0.16	0.15	0.47	0.04	0.05	0.10
Other	1.49	2.05	2.68	2.44	3.52	3.54
Compens. error	*1.55*	*0.57*	*2.6*	*0.48*	*0.09*	*0.62*
SUM (in %)	100	100	100	100	100	100

Source: EU Survey on Cost of Research (2011)

The declining share of EU15 that appears in Table 12 is in line with developments in knowledge intensive companies in EU15. Take for example Bayer and Siemens, both German companies reinforce their R&D activities by the recent opening of facilities in US (Bayer), China (Bayer and Siemens), India (Siemens) and Russia (Siemens)[17]. EU companies in general set up R&D facilities in Asia when they also sell innovative products there, the argument is adapting products to local demand (‘home-base-exploiting’) rather than what is known in the literature as relocation based on ‘knowledge augmenting’ arguments (access to knowledge abroad that complements the home-based stock of knowledge) (Schmiele and Mangelsdorf, 2009). R&D activities become globalised and follow – although hesitantly – the growth of global demand for innovative products. The future trend clearly is stronger than in the past as assessed by respondents and is not confined to China, India or other Asian locations, but applies also to ‘Other EU27’, US and Canada and other locations.

[17] Annual Reports 2010 of both companies.

Figure 22: Share of locations in R&D financed by EU companies (in %).



Source: EU Survey on Cost of Research (2011)

The location shifts are different in the various sectors as is exhibited in the Figure 23 - Figure 26:

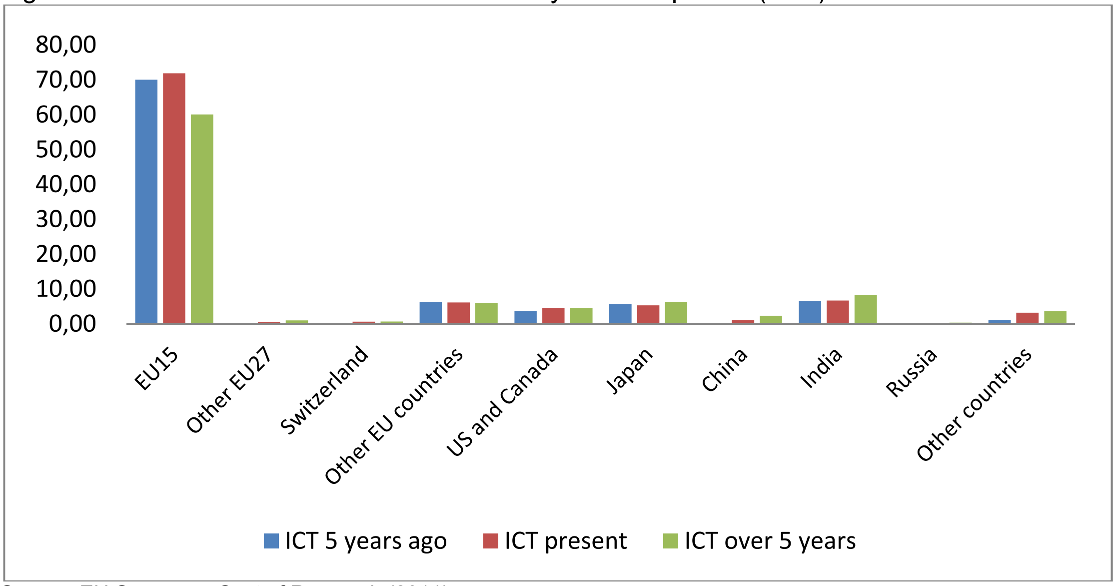
- In ICT the shift from past to next five years is: towards India (from 2.56% to 8.27%), China (from 0.19% to 2.33%) and 'Other location' (from 1.13% to 3.60%) – see Figure 23[18]. The share of EU15 will – according to the respondents – decrease to 60% from 70% 5 years ago.
- In pharmaceutical and chemical industries the shift towards US and Canada (from 10% to 16%) and China (from 0.11% to 2.40%) is particularly strong, the aggregated assessment of the respondents is that the share of EU15 location in R&D will fall to 70% from 81% 5 years ago (see Figure 24).
- In automotive sectors 'Other EU27' gains 5% share in R&D at the expenses of EU15 locations, India will also gain, almost 65% will stay in EU15 from 78% five years ago (Figure 25).
- In 'Other industries' the share in R&D spend in EU15 is expected to fall to 68% over five years from 80% five years ago, this is exhibited in Figure 26.

There can be found a general pattern in scientific literature that economic growth of China and India has led to increasing foreign direct investment, not only in production activities, but also in foreign R&D activities in this region. In the Economist Intelligence Unit (EIU) China and India were mentioned as the world's leading R&D hotspots along with the United States (Asakawa and Som 2008). Regarding particular industries, recent literature reveals that in ICT, R&D investments are still mostly in the OECD area, but is establishing more and more R&D centers in emerging countries, such as China (Shanghai and Beijing), Israel (Haifa), India (Bangalore and Delhi), Russia (Moscow and St. Petersburg), and, to a lesser extent, cities in Chinese Taipei, Malaysia, and Singapore (Vickery and Wunsch-Vincent 2009). Likewise in the pharmaceuticals and chemicals industry, empirical evidence confirms results from the EU survey on cost of research. R&D in these sectors is mostly geographically clustered and located near to relevant university research, whereby this relationship is even stronger for foreign-owned laboratories (Abramovsky et al., 2007). The pharmaceutical and

[18] See also Meijers, H., B. Dachs, and P. Welfens (Eds.): Internationalisation of European ICT Activities. Dynamics of Information and Communications Technology, 2008, XII, 352 p. Springer.

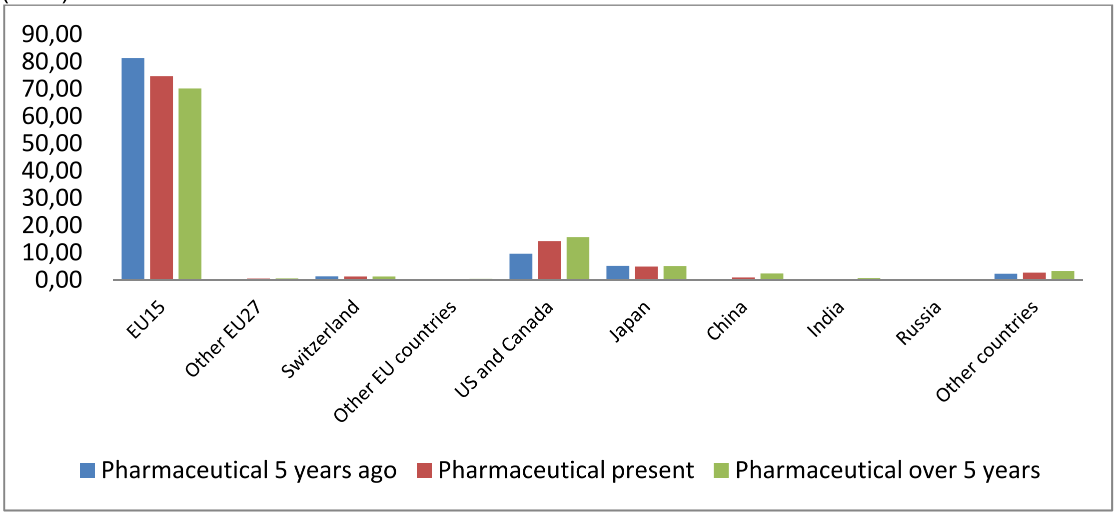
chemical industry traditionally is very strong in the U.S and Canada; however, China is getting more and more important in these industries. As stated by Gassmann et al: (2008, p.111), China has “the world’s fastest growing over-the-counter drug market” and was mentioned as “…the second largest pharmaceutical chemical producer”. Therefore, it is not surprising that R&D in China is indispensable, at least referring to development, i.e. adopting products to the local market. Considering the automotive industries, a large share of production and R&D activities is located in the EU27 countries; this is mainly in the western European countries Spain, Germany and France and in the eastern European countries Hungary, the Czech Republic and Slovakia. Besides ICT, pharmaceutical and biotechnology industries, foreign R&D activities in India are concentrated in the automotive industry (Asakawa and Som 2008). This growing importance of R&D activities in China and India can be confirmed by results from the survey depicted in the figures below.

Figure 23: Share of location in R&D financed by ICT companies (in %).



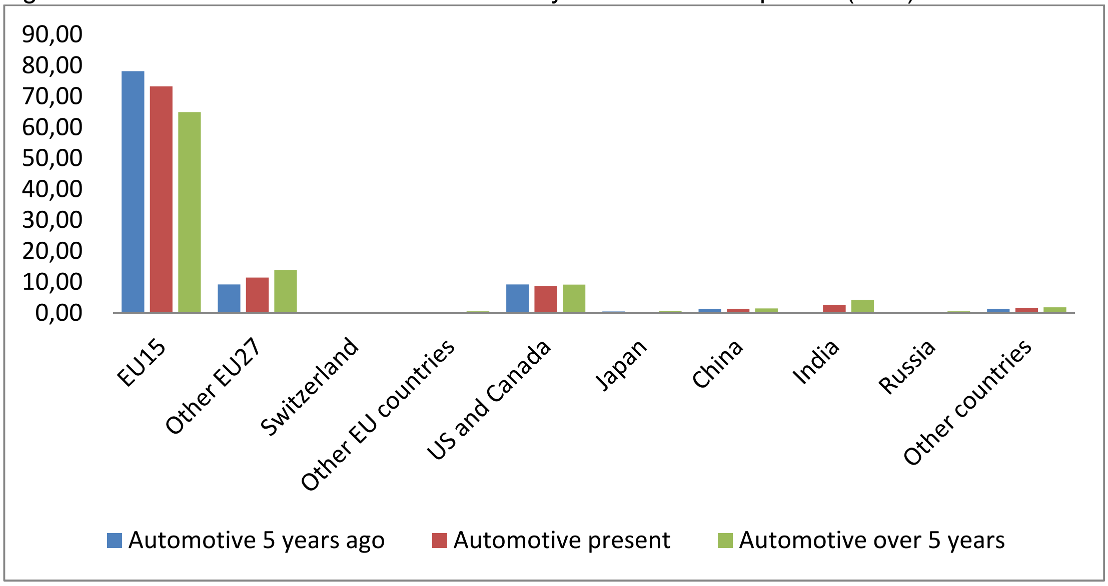
Source: EU Survey on Cost of Research (2011)

Figure 24: Share of locations in R&D financed by pharmaceutical and chemical companies (in %).



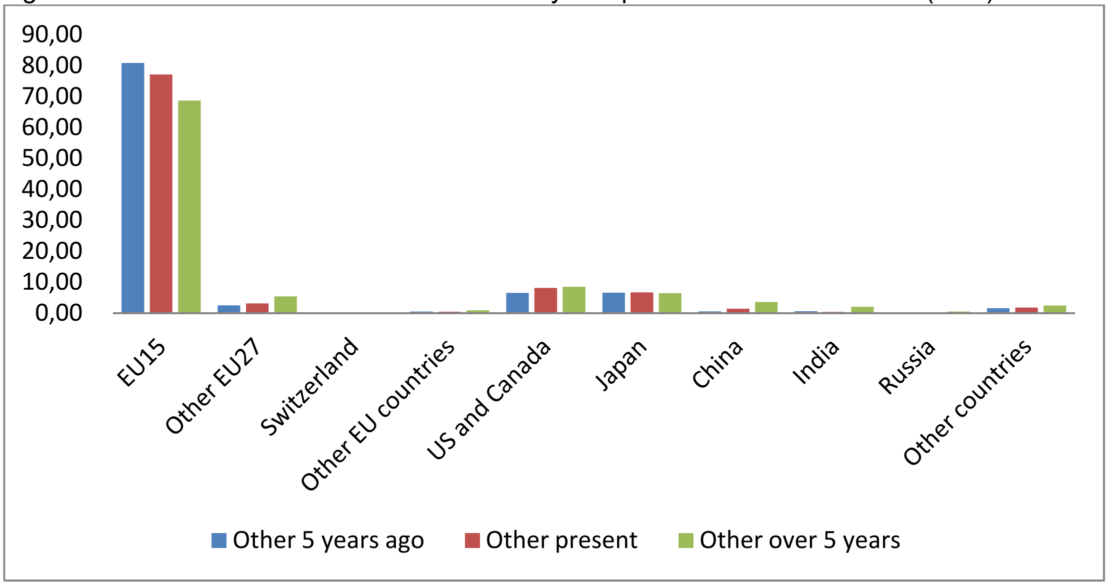
Source: EU Survey on Cost of Research (2011)

Figure 25: Share of location in R&D financed by automotive companies (in %).



Source: EU Survey on Cost of Research (2011)

Figure 26: Share of location in R&D financed by companies in other industries (in %).



Source: EU Survey on Cost of Research (2011)

The **case studies** deliver rich evidence about the development of research cost which complements the interpretation of survey results and provides a more elaborate and detailed understanding of the underlying factors and how managers have and are responding.

Cost development refers to the key elements that comprise research expenditures. **Labour** is the largest of these, accounting for about half of the research expenditures for most of the company we interviewed. Although some interviewees were not able to reveal percentages, they were able to confirm that labour costs are the largest component of research expenditures. Labour includes fringe and wages, and also is related to supporting costs such as training and travel. Some of these costs (notably travel) are considered discretionary. Associated recruitment costs can be significant in industries where it is difficult to attract highly qualified personnel (see for example, the Motorola case).

For Rhodia, increases in labour costs signal greater use of engineers and less use of technicians. For DSM, a major factor in research labour costs is exogenous considerations such as the lack of availability of organic chemists in Europe and the US. Although wage costs have risen, Boehringer Ingelheim's IMP emphasises that good people require good facilities and capital equipment, so those costs have doubled.

Information technology can be linked to labour costs since IT systems often support individual employee productivity. In recent years the price of IT systems has gone down and their performance has increased. In addition, powerful sophisticated computing systems are used for particular (scientific and technological) reasons in R&D; their purpose is not everyday office or laboratory productivity but scientific analysis, computer aided design, simulation and modelling etc. These costs are not related to labour costs but are an independent equipment and infrastructure cost that is context dependent. Both proprietary and bespoke software is needed; grid computing and cloud computing can make large scale computing capacity available at a lower cost than 5 or 10 years ago. Some companies, especially Boehringer Ingelheim's IMP points out the high cost of access to databases and research publications accessible through information technology.

Another substantial category of research costs is capital equipment and **materials and supplies**.

Equipment is especially prominent to GDF Suez, and also a large component for Homag and up to 30% of total costs for Boehringer Ingelheim's IMP. In some industries (e.g. pharma, energy) the most significant cost driver are equipment and facilities, strategy to cope with are various cost sharing models and co-operation arrangements with other research institutes at the same locations, therefore location is very important. In the energy industry for instance, costs are exploding because of the need for demonstrators - capital costs are a key component. The transition to renewables energy production involves the creation of new companies and supply chains, not just diversification of incumbent energy companies. Thus there are new business models dedicated to renewables (and other sustainable development) R&D. It is expected that in general the share of R&D costs for facilities and equipment will increase even if at a slower pace, but there can be important exceptions; quality assurance and standards costs will increase, too.

In the future five years, interviewees suggested that there will be greater use of open innovation methods, in part of manage costs. Fagor Electrodomesticos exemplifies this approach with plans for lower wage costs for R&D in Asia and greater use of worldwide alliances. Boehringer Ingelheim's IMP predicts the share of R&D costs for facilities and equipment will increase but at a slower pace, whereas quality assurance costs will increase.

The non-European cases are especially distinctive in their emphasis on several cost elements. Many of the US companies in the electronics/ICT/semiconductor industry cluster have experienced long-term declines in sales which in turn is reflected in declines in R&D budgets. The US cases make reference to intellectual property (IP) costs, and the importance of maintaining a strong patent portfolio while at the same time managing the costs of this portfolio with greater selectivity in patenting investments. The US cases also are distinctive in their allusions to selling off capabilities as an approach for management of capital and other costs (Motorola, Texas Instrument). The Chinese case (Ruijie Networks) is differentiated by the high percentage of its research costs accounted for by labour (65%) and the ever increasing rise occurring in these costs.

3.3.2 Public Research Organisations

According to the information provided by the respondents, the average public research organisation (PRO) is 62% funded by public sources, while the share of public ownership is 89%. Table 13 below gives an impression of **general information** of the average PRO and the (often small) most frequently encountered PROs in the survey (the so-called median PRO exhibited in the second column from the right). The average PRO has typically a total budget of €39.3 million, 184 researchers and 484 total staff. Because the distribution is skewed (due to a few very large organisations), the median seems more meaningful to characterise PROs then per average.

Because the most frequently responding PROs are much smaller than the average, the median values are also exhibited in Table 13. The total budget for median PROs is much smaller: €6.3 million instead of €39.3 million and the core budget for these organisations is with €2.6 million way below the average of €39.3 million. Productivity measured with ISI publications per researcher (FTE) is with 0.47 much higher in average PROs than in median PROs with 0.22 publications per researcher. Note that ISI publications do not cover the full range of journals, ISI publications do not cover emerging areas very well and impact scores differ between disciplines and even sub-disciplines[19]. Thus, to the extent that small PROs are more engaged in emerging research areas than large PROs, this measurement of productivity gives probably a biased impression of productivity of small PROs[20].

Table 13: Public research organisations in the EU27 - general information.

Public Research Organisations (EU only)	mean	median	N
How much of the total budget is publicly funded?	62.00%	69.00%	46
What is the approximate share of public ownership?	89.70%	100.00%	28
Current total R&D budget (€1,000)	39,300.00	6,392.00	37
Current core R&D budget (€1,000)	33,700.00	2,651.00	33
Capital expenditures (€1,000)	3,555.00	1,586.00	33
Other expenditures (€1,000)	18,000.00	1,631.00	26
All personnel costs (€1,000)	22,800.00	5,428.00	28
Number of researchers	184.16	96.00	42
Number of researchers in FTE	193.16	92.00	42
Number of total staff	484.04	177.50	42
Number of total staff in FTE	453.76	190.00	41
# ISI publications (3 years average)	91.08	20.00	26
# EPO patent applications (3 years average)	10.78	0.00	26
# USPTO patent applications (3 years average)	21.02	0.00	26

Source: EU Survey on Cost of Research (2011)

All personnel cost are in most cases less than the total R&D budget, however there are a number of PROs with very small total R&D budgets compared to total personnel cost. The latter PROs are more than others engaged in other activities like supplying information and

[19] VSNU NWO (2003), Standard Evaluation Protocol 2003/2009 For Public Research Organisations, Vereniging van Universiteiten/Association of the Universities in the Netherlands, p. 10.

[20] In our analysis, we defined as “small” those PROs having a number of R&D employees in FTE less than 177, and as “large” those having this number greater or equal to 177, where 177 is the median value of the number of R&D employees in FTE. We followed this statistical criterion, because of the exiguous number of available PROs exploitable in the survey (64 entities).

advice to the public. Capital cost varies very much from almost zero to more or less equal to all personnel costs. PROs with a large share of capital cost are probably more engaged in (basic) research than in development. The distribution of the public budget as a share of total budget as well as public ownership is rather symmetric.

Cost shares are different for the average and the median PRO. Obviously this is a consequence of the wide variety of cost structures and the low number of observations because of the low response to this question. The main differences with the R&D cost structure of companies are mainly caused by wage costs which are higher in PROs and purchased R&D which is lower than in companies.

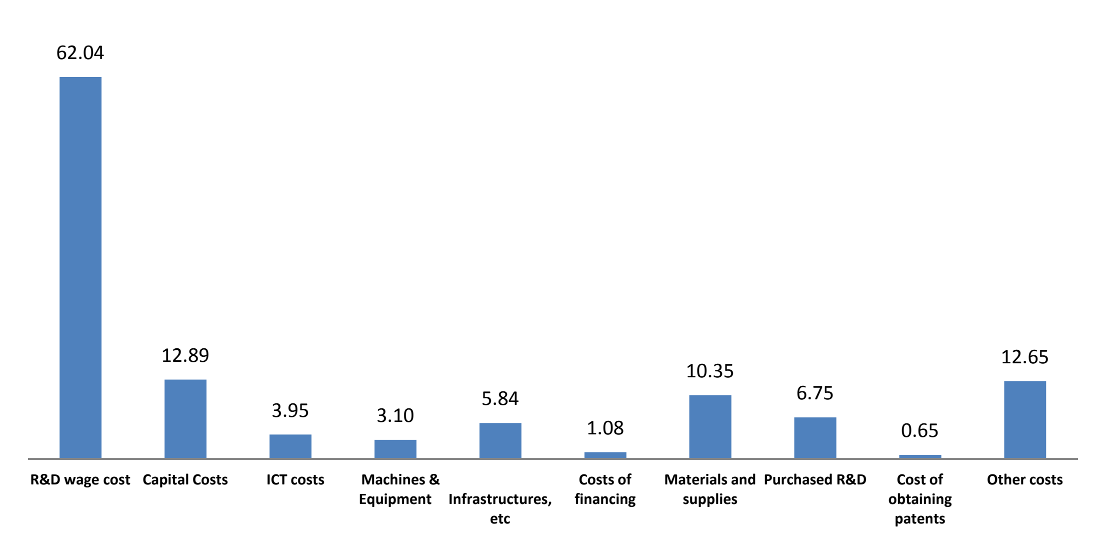
The specification of capital cost in ICT, machines and infrastructures was not well understood by a number of respondents, therefore a correction was applied to these observations. The inconsistency was that the sum of the detailed cost did not equal the aggregate capital costs. As one can see in Table 14 and Figure 27 (graphical presentation), the median values are not very different from the average cost structure, it shows that for large PROs purchasing R&D is a larger cost item than for smaller PRO's. Other costs are very different in kind: it ranges from energy costs and travel, to external services, consultancy and advertising costs. The share of 'other cost' ranges among the cases from 0% to 46% of all costs.

Table 14: Current cost composition of R&D in Public Research Organisations (in %).

Cost shares (PRO)	**Mean**	**Median**	**No. of obs.**
R&D wage cost	62.04	64	27
Capital Costs	12.89	11	26
ICT costs	3.95	3	19
Machines & Equipment	3.10	5	19
Infrastructures, etc	5.84	5	17
Costs of financing	1.08	0	24
Materials and supplies	10.35	9	26
Purchased R&D	6.75	4	24
Cost of obtaining patents	0.65	0	20
Other costs	12.65	9	17

Source: EU Survey on Cost of Research (2011)

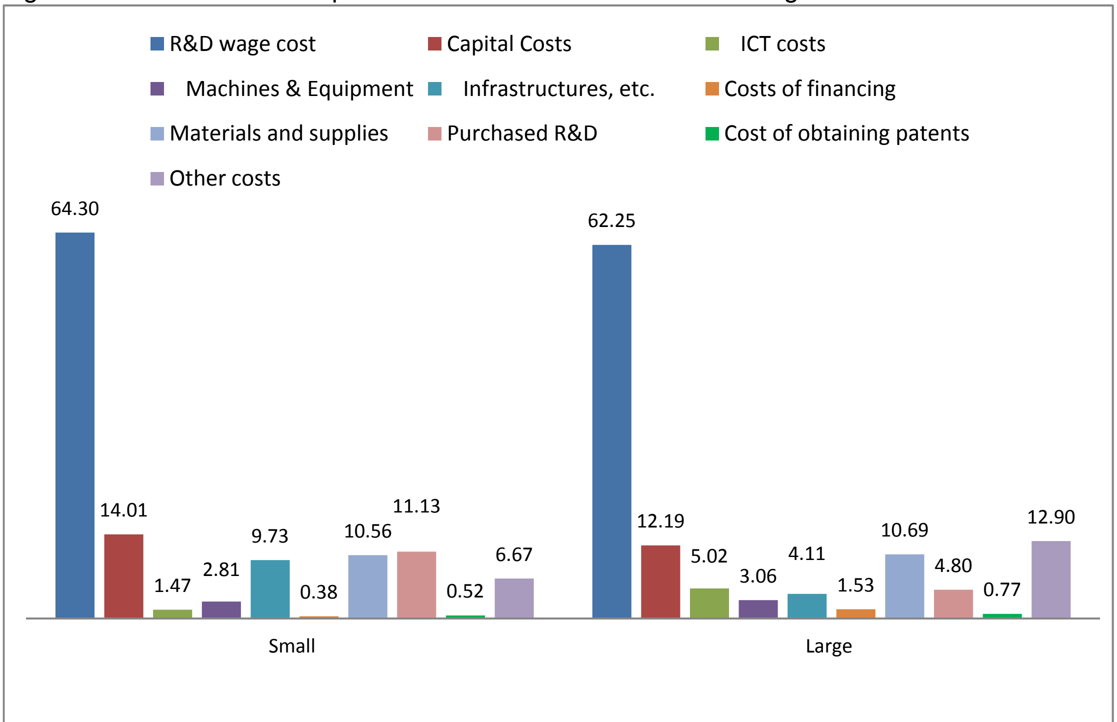
Figure 27: Current cost composition of R&D in Public Research Organisations (in %).



Source: EU Survey on Cost of Research (2011)

Figure 28 sets out the current cost composition of R&D in small and large PROs (although results have to treated with care due to the low number of observations). The size threshold is the median, equal to 177 employees. Anyways, as it can be seen, great differences do not emerge. Small PROs have only comparative higher costs for purchased R&D (11%) against the lower level of large PROs (5%): this probably reflects the need for small PROs to find R&D competences outside the boundary of the company. On the contrary, other costs are higher for large (13%) than for small PROs (6%). Also the structure of capital costs is a little different in the two groups with small PROs more plagued by the cost of R&D infrastructures (as it was quite expected).

Figure 28: Current cost composition of R&D in Public Research Organisations.



Source: EU Survey on Cost of Research (2011)

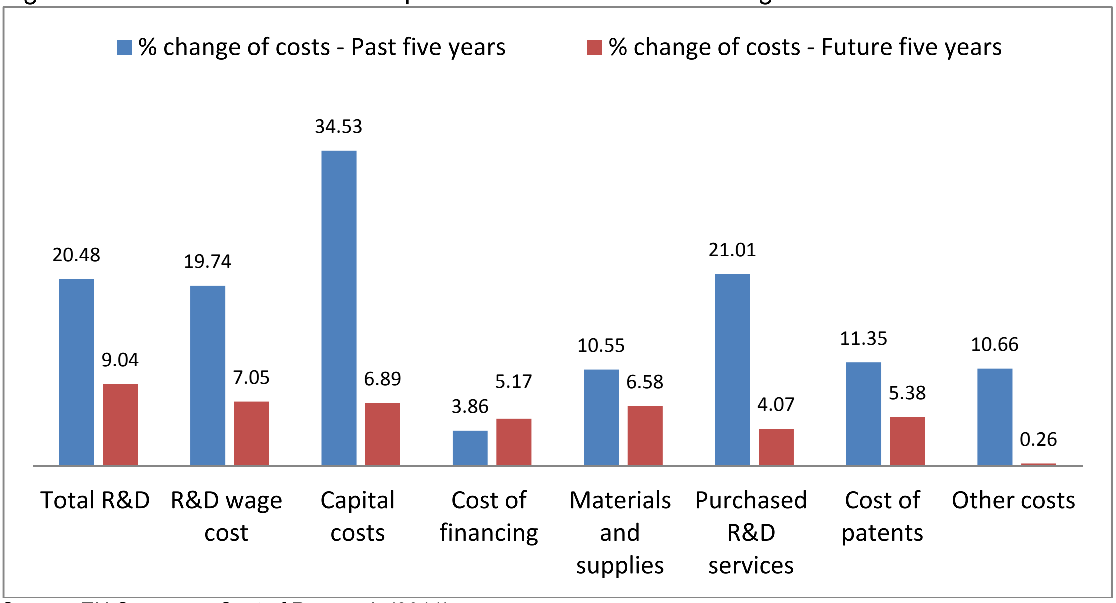
Cumulative cost developments over the past five years as well as the next five are shown in Figure 29. Response rates for this question were very low, hence, for PROs we ended up with unreliable results for this question. Given the low numbers of responses and the very wide spread of the changes in the cost components reported, interpreting these aggregate developments is a very risky affair.

Taking this into account, we can say that total R&D costs will be around the half in the next five years compared with the past, and it will be due mostly to a price effect, while it was due to a volume effect in the past. Because of the large share of wages on total cost (around 60-70%), similarly to the total R&D cost trend, the expected increase of wages for R&D employees will be lower (less than half) than in the past five year, and it will be due to a price effect (1.19, see Table 14). Other volumes and prices are subject to large variations due to the low response rate causing unreliable results.

The expected cost development for the next 5 years for capital costs (6.89%) and purchased R&D (4.07%) is again due mostly to a volume effect, but is based on the information from 16 and 11 organisations respectively and thus has to be interpreted with care.

Given the skewed size distribution for the PROs it may be relevant to see if this is different for small vs. large PROs, but because of the limited response for this item, the possibilities for more detailed analysis are limited.

Figure 29: Cumulative cost developments in Public Research Organisations.



Source: EU Survey on Cost of Research (2011)

There is a rich variety of PROs in Europe. The variety includes a wide range of sizes, discipline or technology focus, and mission. There are different methods of funding and governance and research intensity (the extent to which they focus on producing publications and patents). Scientific publications and patents are heavily targeted in the large PROs, while meeting societal demands with regard to the development and application of specific knowledge is what occupies the median or small PROs.

The case studies show that many respondents already have or expect to have problems to finance R&D. Every year research organisations must adjust the volume of R&D to match budget expectations. There are usually more project suggestions than budgets can fund. In a recession clients and sponsors are likely to impose budget cuts and as corporate clients might have shifted part of their R&D activities to non-EU; this may stimulate a marketing campaign to attract new clients.

The **increase of personnel costs** is quite modest according to the information we gathered by our interviews, particularly as in many countries the salaries for employees in public organisations are heavily regulated and contained by civil service labour relations (e.g. *Tarifverträge* in Germany). In general, the development of personnel costs is in line with the generic development of salaries (in the public sector) which is often bound to the increases of the cost of living. There is limited leeway from the organisation to pay more or above the average. This rather causes the problem to attract highly distinguished researchers. PROs (in specific countries and sectors) have limited scope to attract high level talents on the international labour market. This is less problematic for Phds or younger researchers. It is particularly difficult to attract good researchers and technicians when the economy is growing.

As seen in Figure 29, from the survey capital costs were found as the costs with the strongest increase in the past. The contents of the case studies stress this fact and point out its reasons.

As in general, the **cost for equipment, devices and facilities** were considered by all PROs as the factor which has grown the fastest in the last years – some even talk about dramatic and disruptive changes. Some organisations have specifically a problem with funding of infrastructure as budgets do not cover the necessary investments in equipment, and – if a research institute does not have the best equipment – it is not attractive to industrial clients. In addition, investment cycles are getting shorter and maintenance costs are rising. With EU FP projects, for instance, only a small amount of infrastructure can be funded, which is seen as a problem by some of the PROs. Moreover, this investment is not static, but infrastructures need to be constantly replaced as a result of the increased pace of change. In order to 'stay in the competition', PROs needs to invest. However, it is not obvious that this situation is recent, or is driving an increase in costs.

ICT-based infrastructures have grown considerably. Only standard hardware costs have decreased while software costs and specific hardware used by research organisations have grown. For example, managers of INRA, the network of French public research organizations in the field of agriculture, stated: *"A disruptive change has occurred regarding capital investment, most notably in the ICT infrastructure. The investment needed in that respect has risen exponentially."* INRA expects to have to invest €20 million each year over the next 3-4 years (current annual investment levels are around €3-4 million).

Energy costs are considered by some PROs – depending on the sector – as a significant cost element that has grown in the last 10 years. Energy costs are relevant for those organisations which are for instance using large testing facilities, physical labs, etc.

4 Drivers for the development of research costs

4.1 Evidence from the literature

The identification of drivers for the development of costs of research is an important aim of the COST study. Here we concentrate on the internationalisation of R&D, the organisation of R&D, the quality of the research process, market structure, the role of networks, and patents as possible drivers (or containing effect) for research costs. In some case the exhaustion of a technological paradigm drives R&D costs and causes declining research productivity. Further, an important aspect of the cost of research is the institutional environment in which it takes place, in this context, regulation and policy has a significant impact on the cost of R&D, too.

Management methods can contain costs or increase productivity coincidentally. Management methods are used to strategically focus R&D and to reduce risk; wise R&D investments can generate new business development benefits which outweigh cost efficiency gains.

4.1.1 Internationalisation and organisational changes and the cost of research

The economic importance of the internationalization of R&D has been widely discussed in the literature (Bartlett and Goshal 1990; Hakanson 1990; Howells 1990). Empirical evidence shows that in most cases internationalization of R&D follows the internationalization of sales and production (Birkinshaw and Hood 1998; Archibugi and Iammarino 1999; von Zedtwitz and Gassmann 2002).

Archibugi and Michie (1995) and Narula and Zanfei (2005) developed a taxonomy of the internationalization of innovation differentiating between three main categories and corresponding actors and forms of the internationalization of innovation (seeTable 15): (i) profit seeking firms and individuals internationally exploit nationally produced innovations; (ii) universities and research institutes, as well as national and multinational enterprises search for international techno-scientific collaborations; and (iii) multinational enterprises, which by definition are the only ones being able to do so, carry out the whole innovation process internationally within its boundaries (Narula and Zanfei 2005, UNCTAD 2005, p. 104).

These different categories of engaging in R&D internationally rely on the firms' motives. The literature differentiates between two broad motives: The market motive that is improving the way existing assets are utilized (the market motive largely corresponds to the first category described above), and the knowledge motive (corresponding primarily to the second and third category), denoting the firm's strategy to improve existing assets or to create new technological ones (Narula and Zanfei 2005). These motives originally derive from foreign investment decision strategies, based on the findings from Hymer (1960) and Dunning (1981, 1993), distinguishing four FDI (foreign direct investment) strategies: resource seeking, market seeking, efficiency seeking and asset seeking. The first three FDI strategies can be subsumed to asset exploiting, referring to the market motive, i.e. to different modes of foreign investment decisions aimed at exploiting already existing advantages or knowledge and thus extracting economic value from these. By contrast, asset augmenting (asset seeking) can be referred to the knowledge motive and denotes the firm's objective of "…gaining access to specific competencies which reinforce firm's ability to compete in foreign markets" (Dunning and Lundan 2008, p. 13).

Table 15: Taxonomy of internationalization of innovation.

Category	Actors	Forms
(i) International exploitation of nationally produced innovations	Profit-seeking (national and transnational) firms and individuals	▪ Exports of innovative products ▪ Cession of licenses and patents ▪ Foreign production of innovative goods internally designed and developed
(ii) International techno-scientific collaborations	Universities and public research centers	▪ Joint scientific projects ▪ Scientific exchanges, sabbaticals ▪ International flow of students
	National and multinational enterprises (MNEs)	▪ Joint ventures for specific projects ▪ Production agreements with exchange of technical information and/or equipment
(iii) International generation of innovations	Multinational enterprises	▪ R&D and other innovative activities both in home and host countries ▪ Acquisitions of existing R&D units or greenfield R&D investment in host countries.

Source: UNCTAD 2005 (with minor adoptions), adopted from Archibugi and Michie 1995, Narula and Zanfei 2005

Asset exploiting R&D (Dunning and Narula 1995) or home-base-exploiting (Kuemmerle 1999) covers adapting existing technological assets to foreign local conditions, as these might be consumer preferences, regulations, or environmental conditions, whereas a firm's competitive advantages are widely regarded as a prerequisite (Dunning 1981; Caves 1996; Markusen 2002). The strategy corresponds to traditional views of the organization of innovative activities and FDI, many of them based on the product life cycle theory, theorizing a "quasi-colonial relationship" (Dunning and Lundan 2008, p.13; Narula and Zanfei, 2005) between the parent company and the foreign subsidiaries with rigidly centralized innovation activities, in particular long-term, strategic activities in the home country (Vernon 1966; Kindleberger 1969; Stopford and Wells 1972; Cantwell 1995; Cohen et al. 2009).

Asset augmenting R&D (Dunning and Narula 1995) or home-base-augmenting (Kuemmerle 1999) in contrast, refers to acquire and internalize or create new knowledge and technology in the host country (Narula and Zanfei 2005) assuming that the foreign location provides access to new knowledge complementary to the firm's already existing that is not as easily available in the home country (Ietto-Gillies 2001). Thus, asset augmenting R&D is driven by local knowledge in the host country due to the presence of firms or universities endowed with high quality technology skills and competencies (Cantwell and Iammarino 2003) and favorable framework conditions for R&D and innovation. Narula and Zanfei (2005) assume that foreign subsidiaries follow an asset-augmenting strategy, when knowledge relevant for innovative activities is clustered in a certain geographical area and is "sticky".

Asset exploiting strategies refer to more downstream stages of the innovation process and are associated with demand-driven innovative activities, whereas asset augmenting relates to knowledge creation and internalization of technology spillovers. It is known from the literature that in recent years, a growing number of firms have followed asset augmenting strategies, although the asset exploiting strategy still prevails (Narula and Zanfei 2005; Sachwald 2008). Furthermore, it is notable that in a number of cases the firm's strategy cannot be assigned only to one of those mentioned (e.g. Criscuolo et al. 2005), i.e. firms follow both strategies simultaneously.

The aforementioned strategies of internationalizing R&D are related to specific advantages of overseas locations. These mostly rely on different factors forcing or favoring firms to internationalize their R&D activities. Nonetheless, internationalizing R&D is not only related to benefits but also to costs resulting from decentralization, whereby advantages should exceed disadvantages obviously. Developing an external network structure to gain access to complementary location-specific assets requires time and capital, thus costs of integration evolve. The European Competitiveness Report 2010 (European Commission 2010) summarizes the additional costs of internationalization; Criscuolo (2004, p. 3) recapitulates potential costs and benefits of both firms and home and host countries respectively.

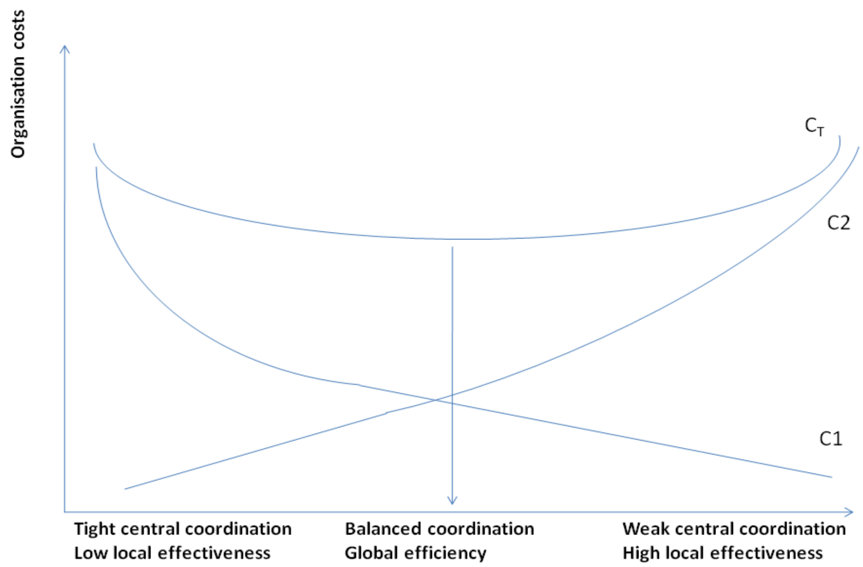
Additional costs of internationalization can be assigned to, first, foregone benefits of R&D centralization and higher coordination efforts, being reflected in reduced economies of scale and scope, second the need to overcome institutional and social hampering factors, and third, costs of and increased obstacles in transferring knowledge within a multinational enterprise, which may be due to geographical and technological distance (European Commission 2010; Criscuolo 2004).

Foregone benefits and higher coordination efforts referring to reduced economies of scale and scope may arise from specialization, more secrecy and a tighter control over core technologies of the firm (Gersbach and Schmutzler 2006, Sanna-Radacchio and Veugelers 2007). The need to overcome social and institutional hampering factors has been discussed in the literature as the liability of foreignness (Zaheer 1995, Eden and Miller 2004) or the liability of outsidership (Johanson and Vahlne 2009). In this context, costs arise when a foreign firm is not sufficiently embedded , i.e. being an outsider in the host country innovation system (Zaheer and Mosakowski 1997; Criscuolo 2004). This could be an explanation for the low share of purchased R&D that was reported by companies in the 'most dynamic regions'. As 'outsiders' in for instance China, it might be more difficult, and take more time to build such purchasing relationships.

One aspect which has not been explicitly addressed so far are labour costs. In the literature on the internationalization of innovation these are linked to capacity bottlenecks. Capacity bottlenecks may result from a limited availability of skilled personnel; may it be an absolute shortage, because personnel with needed qualification is not available, or a relative shortage, because skilled personnel is not available at the going wage level. Empirical evidence (Reger 2003, Boutellier et al. 2008, Lewin et al. 2009) shows that capacity bottlenecks as to the shortage of high skilled science and engineering talent leads to the diversification of R&D, although direct cost advantages, such as labour costs, rarely affect the internationalization of R&D.

Gassman and Zedtwitz (1999) perceive organisational costs of the R&D process as the main drivers for dispersion of R&D activities. Figure 30 exhibits the main cost drivers for organizing decentralized R&D activities. The cost curve C_T is the sum of the cost for central coordination (C_1) and the costs of achieving local effectiveness (C_2) or, mathematically spoken, the sum of the two costs curves C_1 and C_2. The most efficient operation in terms of organisation cost is in this view a balanced coordination – not too tight, not too weak. We have shown that there has been (and will be) a continued shift of R&D activities from EU-15 to high growth regions. In this perspective a new balance was found. Central coordination may have weakened, but local effectiveness in high growth markets seems to be an important motivation.

Figure 30: Minimizing total organisational costs by balanced coordination.



Source: Gassman and Zedtwitz (1999)

In a further analysis of the R&D structure and the efficiency of the entire R&D process various models have been studied by Gassman and Zedtwitz (1999). The R&D Hub model where a central R&D facility coordinates the process, a decentralized R&D model with autonomous R&D facilities and the relative new model of R&D integrated networks. The shift from one organisational concept to another is driven by various factors: opportunities and risk factors, reorganisations and political interest and by smooth transitions rather than quantum leaps.

In addition, more recent studies stress internationalisation and organisational trends to contain costs. These changes across as well as within firms should enable these firms to reduce the cost of research. Indeed the organisation of the R&D process is changing dramatically in three dimensions: linking R&D to business needs, increased use of outsourcing and partnerships and new matrix management techniques (McGuckin et al., 2006).

Disentangling the R&D process into the research part and the development part, research tends to be in the proximity of the headquarters and universities while development is close to manufacturing operations and customers. Drivers of decentralization are the advantages of being in the proximity of knowledge producing locations (home-base augmenting) as far as research is concerned, drivers of development decentralization on the other is proximity to customers and market (home-base exploitation). The larger the customer base and markets the stronger the forces that drive these home base exploitation locations (Kuemmerle, 1997; Gassman and Zedtwitz, 1999; McGuckin et al., 2006).

4.1.2 The quality of the research

An essential characteristic of the R&D process is the quality of R&D. High quality R&D drives the virtuous circle: new appealing products find their way to the customer and boost the firm's profits, leading to more R&D and to again new products. Launching frequently breakthrough products signals high quality research; examples are Apple, Nintendo, Research in Motion, Nokia, Tata and Samsung to mention a few large manufacturing firms. Also unique customer experiences signal successful and high quality research in services sectors as the examples of Google, Amazon, McDonalds, Walt Disney and Verizon Communications show (BCG, 2009).

R&D is not a homogenous phenomenon or activity and there are obviously many differences in quality of R&D process as well as in the outcomes of this process. However, such differences are hard to measure in most cases. Quality of patents might be a useful indicator. Some authors assert that patent quality determines the value of the firm (Lanjouw and Schankerman, 2006). In empirical work it is not uncommon to use a patent "quality corrected" indicator (Messinis, 2005).

Another perspective on patents (quality) is the relation with the value of the firm. This is especially true in the pharmaceutical industry (Lanjouw and Schankerman 2006). The value of the firm is an important factor for choosing the R&D strategy. Hall et al. (2007) comes to another conclusion: patent quality contributes modestly to the value of the firm but R&D expenditures and it is the stock of patents (with USPTO and EPO registration) which is important for the value of the firm. Zeebroek et al. (2009) asserts that EPO patents held by EU-firms are more valuable than USPO patents, while software patents are quite differently valued in EU or US.

Despite knowledge doesn't depreciate, R&D capital depreciates because as time goes by the value of dated knowledge diminishes (Mamuenas 2006; Lev and Sougiannis 1999). Firms do know (very well) the aim of research and once marketable application has been found, a dedicated business unit carries out the development phase and delivers it to the market (Dougherty et al. 2003).

However, a direct way to show causation between R&D and business success is hardly possible; therefore, most of the literature reverts to indirect methods to exhibit the trends in R&D, the quality of R&D and the measurement of the process of R&D, based on questionnaires and micro data. In the management literature new product performance, for instance, is assessed by profitability and impact on the firm. Performance is driven by high quality new products, a clear strategy and adequate new product resources, especially people and funding (Cooper and Kleinschmidt, 1999).

To conclude, the internal process quality impacts on the costs of research, next to direct costs such as the labour costs of the researchers and the capital costs, on the organisation and location of the research process as well as on the quality of this process. Obviously these factors are not entirely independent and may thus be linked to each other. In order to get a more complete picture on the cost of research one might like to know whether indeed there is an "optimum" organisational structure to minimize cost as suggested above in Figure 30. So indeed a loosely coordinated structure of autonomous R&D entities would be more efficient/cost effective than very strictly coordinated or very weakly coordinated projects. Second, though quality of the R&D process seems highly important in many cases, it is hard to measure.

The question that remains after this overview of the innovation literature is: when does high quality research outweigh its costs? In other words when an increase in cost of research produces an even higher increase in the quality of the research then it is rational not to bother about the cost of research, in practice however costs have been paid long before the quality is revealed.

4.1.3 Market structure, scale economies and the research process

Firms can be classified as high- medium or low R&D intensive (see OECD, 1994). However, for our purpose such an empirical classification of industries based only on the ratio of sales to R&D expense provides not a very practical classification of industries because competitive as well as oligopolistic and monopolistic industries are brought together in the same class. Moreover, strategies may differ among the firms: strategic patenting, building patent thickets, offensive and defensive blocking for example may be strategies for some firms but not available for other such as SME's. Therefore, for our purpose we need a classification that elucidates the cost structure of the research process given the market structure and the complexity of the technologies.

Sutton (1991, 1996, and 2006) develops a general applicable characterization of the research process linking "technology" with market structure in which firms operate. Under "technology", we understand the different pathways used for R&D. Market concentration is an important characteristic of the market structure and provides firms – given their scale – more or less possibilities for defining and following strategic options. In the competition process firms may choose a certain level of research intensity as an option apart from price and product differentiation so R&D expenditures as well as the direction of R&D becomes a strategic option to the firm. This in short – together with the context in which research is carried out and the internal factors as described above – largely determines the costs of research. So a good proxy for the technological factors relevant for the market structure is the research intensity together with the number of technologies practiced in a firm. This Suttonian hypothesis provides a basis for linking research intensity[21], the number of technologies with product market characteristics and research strategy. It is assumed that research-intensive industries that are involved in many technologies exhibit in general high concentration. But when the number of technologies is low, the concentration in the industry tends to be also low. Economies of scale, vertical and horizontal differentiation, and concentration determine the market structure and in our view these characteristics sufficiently describe the differences between markets and technological factors.

It is widely assumed that economies of scale and scope positively affect research productivity (Teece 1980). Research productivity in the broadest sense is to be related to success in innovation. Success in innovation, in turn, refers to research output, for which various measures have been used so far in the analysis of the relationship of scale and scope and research productivity; these are e.g. patents (Bound et al. 1984, Henderson and Cockburn 1996, Cockburn and Henderson 2001), major innovations (Acs and Audretsch 1988) or the advancement to the next innovation stage (referring to pharmaceutical research[22]) (Plotnikova 2010, DiMasi 1995).

Size and diversity are found to be important advantages of R&D activities (Cockburn and Henderson 2001). Chandler (1990) suggest that the research process itself allows for significant economies of scale; Arrow (1962) and Teece (1980) argue that research and the production of new knowledge should be subject to considerable economies of scope. *Economies of scale* arise from fixed costs. These might be costs of running research laboratories, costs of maintaining a high quality of personnel or costs arising from legal and regulatory expertise (DiMasi et al. 2005, Plotnikova 2010). Large firms may be able to spread

[21] The ratio of R&D outlays to sales

[22] The innovation process in pharmaceutical research can be divided into several stages: starting with drug discovery (new chemical entity), and preclinical testing (both referring to "research"), these stages are followed by clinical trials ("development"), which comprise three subsequent phases of testing and an official approval (FDA (Food and Drug Administration) review), necessary to produce and distribute the drug over-the-counter. After these stages additional R&D activities may take place (Plotnikova 2010, pp. 3-4).

these fixed costs of research over larger R&D projects and over a larger expected sales base. Further, large firms may have advantages in securing finance for risky R&D projects, as size is correlated with the availability and stability of internally generated funds (Cohen, 2010; Panzar and Willig1981). *Economies of scope* in R&D mainly arise from internal knowledge spillovers. Firms may benefit from diversified research and innovation activities through the exchange of knowledge across various projects together with a firm's ability to incorporate knowledge from related fields (and across R&D locations) into a R&D project (Henderson and Cockburn 2001, Plotnikova 2010). Moreover, diversified multi-product firms may provide economies of scope by reducing the risk associated with prospective returns to innovation (Cohen 2010).

Empirical evidence of scale and scope economies and research productivity to a large part refers to pharmaceutical research. The studies done by Henderson and Cockburn (1996) and Cockburn and Henderson (2001) analyze the drug discovery ("research") stage (1996) and the drug development ("development") stage (2001). The first study reveals that larger research efforts are more productive due to economies of scale and moreover leading to economies of scope by sustaining diverse R&D projects that capture internal as well as external knowledge spillovers. Focusing on development instead of research Cockburn and Henderson (2001) found in contrast a strong correlation between the diversity of firms' development efforts and the research productivity of individual projects, but no scale effects per se. Empirical evidence, however, does not show inconclusive results: Danzon et al. (2005) found that a firm's diversification not inevitably leads to increased productivity in the development stage of the innovation process. Research productivity is positively correlated to firms whose experience is rather focused than diverse in its innovation activities ("diseconomies of scope"). Thus, diseconomies of scope may evolve when fixed costs and knowledge cannot be shared across diverse research projects and difficulties of managing a large R&D portfolio may arise. To summarize, importance of various factors seems to vary according to the different stages of the innovation process and moreover may result in decreasing marginal effects of economies of scope (inverted-U relationship between scope and research productivity) (Henderson and Cockburn 1996).

4.1.4 The role of networks

External effects or network effects are of utmost importance to the R&D process. In fact, large parts of the so called endogenous growth literature are built on the idea of external effects presented as the accumulation of knowledge and human capital that is non-rival (e.g. Lucas 1988; Aghion and Howit 1992). The general idea is that research results are open to the public and thus available to other researchers that can build on existing knowledge and thus further advancing the "knowledge stock" by doing so. This implies that if exiting knowledge is freely available it has a large impact on the cost of research, at least as seen from such economic perspective. Research networks in a more narrow sense as relations between people and researchers have also a large impact on innovation and give the R&D process more dynamics. Three variables are important here: i) technological distance between (potential) partners (measured by the average correlations between the local firm's technological profile and that of each alliance partner), ii) network density (measured by the ratio of the number of actual alliances to all possible alliances) and iii) betweenness centrality (measured by the fraction of the shortest paths of alliances between other companies that pass through the focal firm). Successful exploration requires a delicate balance between the "twin tasks" of novelty creation and efficient absorption on the other. The position of a firm relative to others in the network is not the full story, R&D intensity, density and the above described mechanism between R&D effort and market share are important too (Gilsing et al. 2008).

Networks are of course not restricted to private parties but can involve public research organisation and universities, too. Transparent and unambiguous regulations with respect to ownership titles and property rights are an important element in the role universities can play in innovation capacity in a local economy. An appropriate environment is necessary to transform the potential university's contribution to innovation in the local economy. It is also a matter of culture the right mix of incentive mechanisms, targeted to the research groups as well as to the individual researchers; exploitation of research outcomes requires extra efforts and these effort should be rewarded properly. Management should be decentralised and should be able to decide for how to proceed with funding future research projects and to grasp opportunity to market (Debackere and Veugelers, 2005). Therefore the relation between public and private research is the subject of several studies that investigate the connection between the two: Guellec et al. (2000) (about 13% public finance of private R&D improves the R&D budget and the quality of the work); Klette et al. 2000 and Lööf et al. (2005). In other words industry-science links can be seen as important networked connections between actors that further knowledge transfer from knowledge creator to knowledge users. Economic performance (innovation & productivity) thus is also the result of the nature and the intensity of interactions and learning processes among producers and other actors.

Over the last decades, multiple insights have been gained (both theoretical and empirical) as to how "effective" industry-science links can be fostered through the design and the development of university-based technology transfer organisations (Debackere and Veugelers 2005). It is just like Triple helix an imagination of interaction between industry, academia and government (Etzkowitz and Leydesdorf 2000). However, firms with open search strategies, with higher R&D intensities that are of certain size, are more likely to draw from universities in their innovation activities while these interactions (between universities and industrial firms) are largely indirect, subtle and complex. R&D has two faces indeed (Cohen and Levinthal 1989, 1990): absorbing knowledge from outside is closely related to the generation of new knowledge within the firm (Laursen and Salter 2006).

Research networks can be seen as infrastructure for knowledge diffusion in EU Regions. These networks make up virtual regional innovation systems might bridge the gap between global research activities and local diffusion activities. Large research organisations are critical for bridging the gap between research and diffusion because they possess the financial, technical, human, and location resources to manage the ensuing complexity (Cassi et al., 2009).

An important catalyst in the process transfer and diffusion of knowledge is open innovation in global networks (OECD, 2008). Open innovation brings more R&D options to existing ones: the R&D budget is not entirely spent in-house. Open innovation is about collaborative methods applied in R&D. The current global innovation climate impact the national (regional) innovation systems. Open innovation is most common in ICT and pharma-biotech and increasingly important in automotive and aerospace. Four factors determine the potential for open innovation: Opportunity condition: how easy is it to innovate?; Appropriability condition: how easy it is to protect ones innovation (invention); Cumulativeness: what is the meaning of today's innovation for tomorrow's?; Ability to carry out multi disciplinary and apply cross functional complex R&D?

4.1.5 Research costs in the pharmaceutical industry

Innovation economics literature devoted to the pharmaceutical industry stands out in their focus on the analysis of the cost of research. These costs are considered to be soaring and the risks and rewards in the pharmaceutical industries are seen as the result of a complex interplay of technological, economic and institutional factors. The studies published during the last 40 year are illuminating: it is shown that during the last four decades R&D costs are soaring indeed. Cost might be soaring indicating good investment opportunities, but there is growing evidence that research productivity is declining driving opportunity costs.

Institutional factors, like the conditions and requirements for clinical tests are important drivers of these costs. The US Government General Accountability Office states that regulatory issues are hampering drug development, new drug development: science, business, regulatory and IP issues[23] implying a huge burden on R&D in pharmaceuticals. Tighter regulation and legislative intervention prolonged the time span between invention of a new drug and the introduction to the market with 10 years. In the course of time new regulations has led to longer approval times, stricter testing rules and criteria and higher cost of research: Prior to 1962 R&D approval time was 5 years and the costs per new compound (or new chemical entity of NCE) were rising slowly with time. After new regulation in 1962, development costs for new drugs rose steeply: especially the costs of clinical trials while the time span from birth to approval now stands on 15 years (Hansen 1979; Di Masi et al. 1991, 2003)[24].

Pharmaceutical research have changed for a large part from chemical research into biological research, with the implication of a declining significance of the scale factor in the research and more emphasis on understanding of the functioning of the human and animal body. Scale however remains important in the testing phase of a new medicine, while further changes in the logic of research are imminent as a consequence of technological change – the human genome, the Internet, etc.

The soaring costs of pharmaceutical research has been criticised by some authors; they blame the development of non- innovative or “me-too” drugs. Other arguments against soaring research costs are related to the methods and data used to estimate the cost of research in the pharmaceutical industries.

Conclusions are that the cost of research has increased because:

1. Other (bio)technologies are being used nowadays instead of chemistry based techniques
2. Research is more focussed on degenerative illnesses
3. Regulatory requirements became more tough; especially the drug approval process
4. Productivity of research fell, and as a consequence proliferation increased in big pharma firms while specialisation increased in SME’s
5. Branded generics give rise to a mixing up research and marketing costs.
6. Due to the rising R&D costs market concentration will increase making entry of the market more costly.

The Tufts Center for the Study of Drug Development is a well-known institute of Tufts University in Boston (US) involved the research of drug development costs.[25] Following their cost estimation methodology the average R&D cost of a “new chemical entity” (NCE) in $ of

[23] www.gao.gov/products/GAO-07-49 (accessed 21 October 2008)

[24] Ruwart (http://www.ruwart.com/AAPS.pdf) asserts that the thalidomide tragedy in US led to the 1962 Kefauver-Harris Amendments that impacted dramatically pharmaceutical manufacturing, labeling, advertising, and development. Since that time - according to this author - the costs of developing pharmaceuticals exceed the benefits by a factor 100.

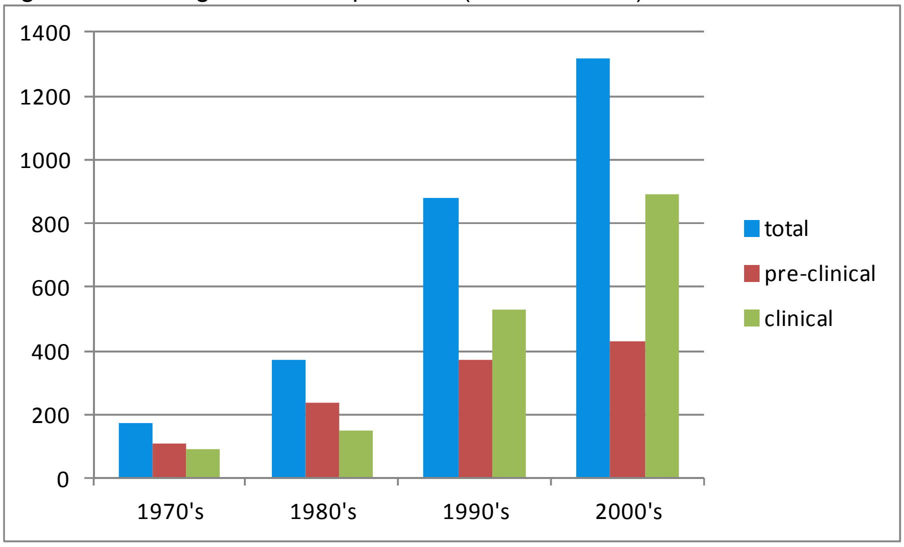
[25] For a summary of the regarding drug development costs see their backgrounder “A Methodology for Counting Costs for Pharmaceutical R&D” available at: http://csdd.tufts.edu/files/uploads/a_methodology_for_counting_costs.pdf

2005 soared to $ 1.3 billion in the 2000's from $135 million in the 1970's, this amounts to an annual rate of 7.6%

Since Hansen's (1979) review of the history of the costs involved in the discovery of a NCE and getting it reviewed, approved and introduced to the market over the period 1963- 1975[26], it became clear that the capitalised costs of a NCE was $ 54 million in 1976 $. It took almost 5 years to get a NCE on the market, after its discovery that took 3 years to complete. Therefore discovering a NCE is one thing, getting approval from the authorities is another thing[27], while the rate of success was quite low: on the average 7 out of 8 fails got approval during this time span.

Figure 31 shows the continuous increase of R&D cost per NCE from the 1970's onward to the 2000's. Apart from the steep increase in costs it turns out that since the 1980's clinical R&D costs has been soaring to 2/3-rd from 1/3-rd of total R&D costs.

Figure 31: Average R&D cost per NCE (million 2005 $).[28]



Di Masi and Grabowski (2007) aim to get a sense of the research costs associated with the discovery of a new drug. The average pre-tax R&D resource costs for new drugs (in this case biopharmaceuticals) consist of cash outlays, the costs incurred in the development time and finally the time obtaining regulatory market approval. Di Masi et al. (2003) use data based on the Tufts dataset.[29] A significant part of the cost of research in pharmaceuticals is contributed by the time that elapses before final approval of new drugs. Main driver of these costs of capital is the cost on equity because all firms in the Tufts CSDD database have less than 1% of their market valuation put into debt. The average cost of capital of the seven biotech and

26 The data came from 14 pharmaceutical firms and covered the period 1963-1975 of NCE's first tested in man after 1963

27 Hansen distinguished eight stages of the drug development process: (1) discovery, (2) preclinical testing, (3) patent filing, (4) phase I human (toxicity) testing, (5) phase II human (pathological) testing, (6) phase III human (long term) testing, (7) long term animal testing, (8) new drug application.

28 This figure has been composed using the work of Hansen 1979, DiMasi et al., 1991, 2003, 2005 and Di Masi and Grabowski, 2007. The data has been recalculated using the US GDP deflator. The costs are expressed as capitalized cost per successful NCE. Thus taking into account the ratio between successful and total NCE discovered in the period under consideration (i.e. rate of success). A NCE is successful in this respect when the FDA has admitted it, while capitalization is based on the cost of capital using a CAPM framework and the time lag between pre-clinical and clinical research and admission.

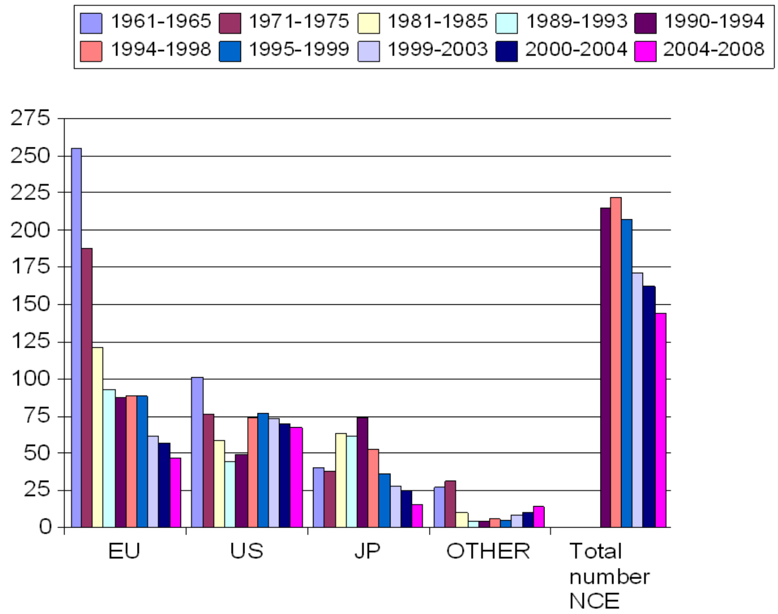
29 This data cover the period 1993-2003, with 7 biopharmaceuticals based on 522 compounds (278 recombinant proteins and 244 mAbs (monoclonal antibodies).

speciality firms in the sample was 19% and 14% in real terms. Based on interviews the authors found that most large pharmaceutical firms used 12-15% as the level of nominal cost of capital (Grabowski et al., 2002). During the period under consideration the inflation was 3% bringing the real cost of capital (RCoC) on the 9-12% level. Di Masi et al. (2003) conclude that the price of R&D costs of new drugs from a survey of 10 pharmaceutical firms increased almost 8% above the general price inflation in the US.

However, some authors (e.g. Light 2007) criticised the Tufts cost estimation methodology. The core of the critique is that the data used in the Tufts studies are not publicly available, the definitions are vague, e.g. it is not clear how the cost of preclinical research has been assigned to a successful NME, while all government support is not accounted for.

Is there a lack of productivity in the lab? Some recent data shows clearly that as far as the numbers of NCE are concerned there is a clearly declining trend in NCE introduced in the periods (see Figure 32) with the exception of the other countries (developing countries).

Figure 32: New chemical entities introduced per period.



Source: www.epfia.eu,

According to the Royal College of Physicians (RCoP, 2009) the lack of scientist in the UK with appropriate “in vivo” [30]skills is particularly threatening research productivity. The low supply of scientists with in vivo skills is related to a decline in the study of the practical aspects of animal physiology and pharmacology at university.

To conclude, the cost calculations regarding drug development cost in pharmaceuticals serves very likely a political motive. It is extremely focussed on showing how expensive drug development is. However, only the most expensive therapeutic classes are reviewed. The

[30] This is animal research.

methodology is based on capitalisation[31] of research cost which in general is not allowed (neither in the US GAAP or IFRS accounting rules) and clearly serves only the purpose of boosting cost of research. Government support is abandoned altogether in the calculations. In contrast to the $1.3 billion R&D cost for a new blockbuster medicine, the average R&D cost per new medicine is only $108 million ($76 million after tax benefits). The problem with many of the new drugs is that they are often not very much better than existing drugs and their development takes therefore a long time and requires many resources.

From the cost studies in the pharmaceutical industry it hence can be concluded - without doubt - that regulatory costs have increased dramatically, while the number of patents declined in the US, Japan and EU – between 1960-2008 – and many of the new drugs are hardly better than existing ones. The conclusion for pharmaceuticals is that the cost might have increased mainly due to regulation, reduced (research) productivity and much larger clinical trials than in earlier times. Other costs might have contributed to the increase but much less than the previously mentioned drivers. The diminished productivity is very likely the consequence of a shift in "technology". Biotechnology research changed the industry from chemistry based research as used in the past into understanding diseases. This is quite different from the older "trial and error" approach of drug discovery. In the future genomics is expected to introduce an even more dramatic change in methods and hence business model. Probably the largest possibilities to reduce cost are another way to organise and manage R&D in order to keep R&D focussed, to transfer knowledge and in doing so to keep the cost in check (see below).

4.1.6 The patent system

The patent system is very relevant for studying the cost of research. On the first hand the number of patents is often seen as a measure of output of the research process (see above). In addition, patenting is associated with costs.

There are many institutional (legal) and economic (market) differences that have an impact on patenting behaviour of firms. We know that some patent classes (Biotech, telecom, audio/video/media, and computers) exhibit strong growth while others (chemistry, handling and processing) are on the decline. The changes in the US laws regarding patenting of software and its impact on firm behaviour is an outstanding example and these changes caused an enormous growth of patent applications whereas the underlying research processes did not or not significantly change.

Patent productivity varies widely over the industries. From the empirical literature it appears that there are strong indications that pharmaceutical patent productivity declined while software patents are booming. Software patents are booming due to changes in patent law; especially since 1981 due to "Diamond vs. Diehr" court decision in the US and more so in 1994 due to In Re Alapat.[32]

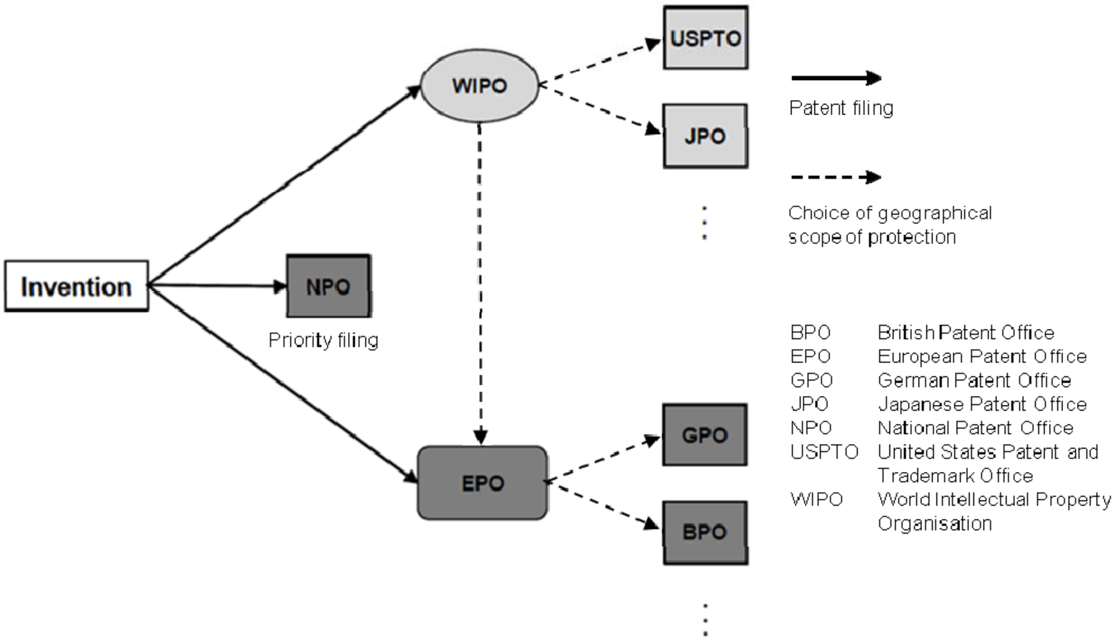
Patenting behaviour is highly region and sector specific and includes various aspects of strategic (market) decisions that are not or not directly related to the research process itself. This implies that the number of patents does not necessarily correspond with the underlying research efforts such that patent statistics are not directly useful to obtain insights in the cost of research.

[31] Using a rate based on the yield on equity.

[32] http://digital-law-online.info/cases/31PQ2D1545.htm

Some studies are dealing with the costs of patents and its evolution in the past. Costs of patenting have to be decomposed according to the granting process at national and international patent offices. Therefore, a short overview (Figure 33 below) over the patenting process is to be given. Patents can be filed at national patent offices (NPO), the European Patent Office (EPO) or for an intended greater geographical scope of protection at the World Intellectual Property Organization (WIPO). Once a patent is granted, it has to be validated at the relevant NPOs; if filed at the WIPO, protection can be applied for, besides other members of the PCT (Patent Cooperation Treaty), at the EPO and its corresponding contract and extension states.

Figure 33: National and international patent offices.

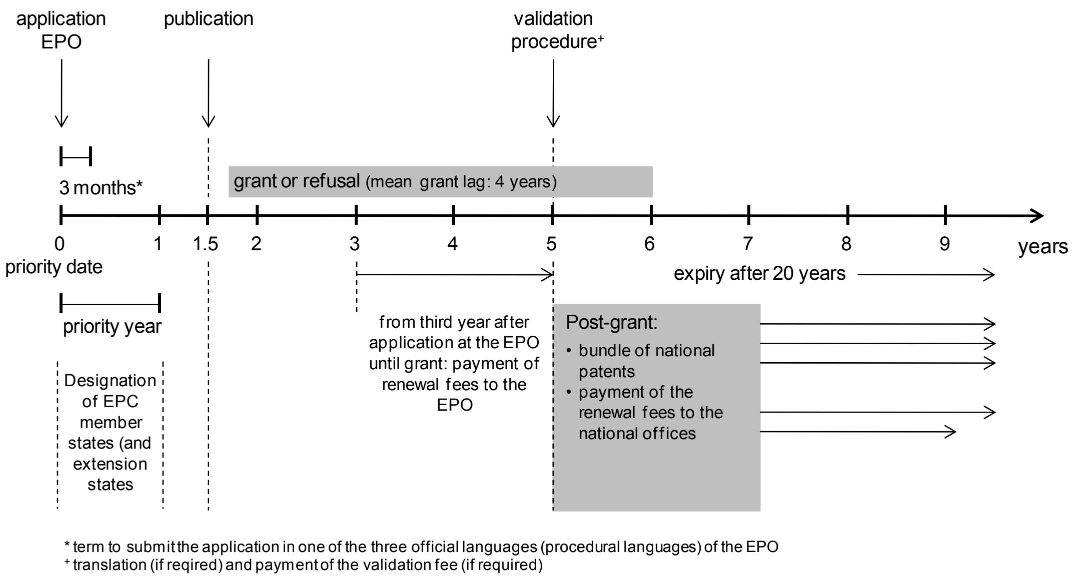


Source: Scherngell 2007, p. 22 (minor adoptions)

Costs of patenting at the EPO are related to (i) external services, (ii) translation, and (iii) maintenance and (iv) the process of patenting (van Pottlesberghe and François 2009). Furthermore, potential costs of enforcement of litigation issues can arise. *Service costs* consist in the writing of the patent and filing to a patent office. *Translation costs* arise, as the patent must be filed in one of the official languages of the EPO, i.e. English, German or French (procedural languages). After granting, the European patent has to be validated at national patent offices *"in one of its official languages at his option or, where the state has prescribed the use of one specific official language, in that language"* (Art. 65(1) EPC). This is to be done for each country, where protection is required. Translation costs vary regarding the size of the patent (number of pages) and geographical scope of protection. *Maintenance costs* refer to renewal fees, which have to be paid every year (up to a total of 20 years from the priority date on a country by country basis varying significantly across national patent offices. *Process costs* encompass procedural fees up to grant, such as filing fees, search fees, examination fees, country designation fees, and grant fees. Furthermore, validation fees are to be paid to national patent offices for the publication of the translated patent (van Pottlesberghe and François 2009; van Pottlesberghe and Mejer 2008).

The European patent system has been criticized above all due its complexity and related costs, in particular referring to its high level of fragmentation and translation requirements, which make it the *"most expensive, most complex patent system in the world"* (van Pottlesberghe and Mejer 2008, p.2). Therefore, two initiatives have been proposed within the European Patent Convention (EPC) legal framework: at first, the London Agreement (LA) aiming to reduce the costs of translation by reduced translation requirements. Second, the European Patent Litigation Agreement (EPLA), which tackles the problem of legal uncertainty, and hence purposes to provide a more homogenous interpretation of the validity and scope of a European patent by implementing a centralized European court for patent-related litigation (van Pottlesberghe and Mejer 2008).

Figure 34: Application and renewal procedure at the EPO (directly filed with the EPO).



Source*:* Harhoff et al. 2009, p.1425

Empirical evidence reveals somewhat contradictory results. Peeters and van Pottlesberghe (2006) and Park (2003) find no causal relationship between perceptions of high patenting costs and the firms' actual innovation behavior. The great part of empirical literature, in contrast, shows a rising propensity of patenting when fees are reduced. De Rassenfosse and van Pottlesberghe (2007, 2008) find that the fee policy at the EPO (fees have severely decreased over the nineties, converging towards the level of fees in the US and Japan) has significantly contributed to the rising propensity to patent. van Pottlesberghe and Mejer (2008) simulate that patenting costs were reduced by 20 to 30% since the enforcement of the LA, leading to an increase (eight to 12%) in patent filings, though, the relative cost of a patent still remains five to seven times higher than in the United States. Harhoff et al. (2009) find fees have a significant negative impact on geographical scope chosen by the applicants. We can therefore subsume that the implementation of cost-reducing policy interventions significantly increases the propensity of both patenting and the number of countries sought for protection. Costs of patenting at the EPO, however, remain high compared to all other patent offices, though are constantly decreasing.

4.1.7 Industry-specific cost drivers

Studying the relation between research and innovation there are important differences between industries. In the semiconductor industry, basic research is highly concentrated and most firms are linked to the knowledge base through research institutions. Also labour mobility is highly important as a source of knowledge diffusion in this sector. This is in contrast with the pharmaceutical industry where most firms perform basic as well as applied research.

R&D costs can be understood in light of the key drivers of costs in their industry. For example, the top industries in the 2007 EU Industrial R&D Investment Scoreboard include pharmaceuticals and biotechnology, technology hardware and equipment, software, and transportation (e.g. automotive, aerospace) (EC 2007). Among the factors that influence R&D costs in these industries are the specific characteristics of the research that they typically undertake and the kinds of facilities and equipment engaged.

Some of these industries are anchored in laboratory research. Laboratories have often been distinguished as wet or dry laboratories (Lenhard et al. 2006). Wet laboratories are typically associated with pharmaceuticals or chemicals industries. Their R&D costs have the distinctive feature of addressing such laboratory costs as filtered chilled water and vacuum and/or gas systems; equipment such as toxic monitors, exhaust fume hoods, eyewash and shower equipment; and materials such as animals, biological and/or physical agents, and DNA. Some of these distinctive costs are one-time start-up costs involved in setting up the wet laboratory, whereas others follow the ongoing cost of materials. R&D health and safety, regulatory monitoring, and safe waste disposal costs also can represent important factors in wet laboratories. Dry laboratories are typically associated with electronics or instruments industries. These laboratories are often centered on specialized equipment and environments, such as clean rooms, that enable the use of this equipment. Costs may follow the use and maintenance of existing equipment as well as the periodic acquisition of new equipment. Both wet and dry laboratory research requires specialized labour capabilities.

Sectors can also be distinguished by whether their R&D is large scale or small scale. Aerospace and energy industries could be considered to fall in the former category. (Nolan and Zhang, 2003) Large scale R&D costs may include suites of instruments, large scale testing and prototyping equipment, metrology facilities, substantial power and safety requirements, specialized water, air and gas systems, and reliable monitoring systems and maintenance. Training and the costs thereof are important to the safe and effective operation of large scale R&D. In contrast, some laboratories may be considered “small scale.” For example, some aspects of nanotechnology research involve the use of desktop size scanning probe microscopes (such as atomic force microscopes or scanning tunneling microscopes) or electron microscopes (such as transmission electronic microscopes). These microscopes allow for visualization, measurement, and feature characterization of nanoscale materials (Lux Research 2008).

While all industries use software to some degree, some industries are particularly software intensive. These include development and dissemination of computer software systems and packages. Much R&D in the services sector involves software development, modelling and programming. In many cases, such R&D is undertaken in standard office suites with desk-top work stations or client computers connected by networks to servers and the Internet. The declining real costs of information technology have underscored personnel costs as a driving factor in innovation in this sector of R&D. However, in some cases, there are requirements for larger-scale computing and data storage facilities which require specialized rooms, power, cooling, and maintenance capabilities.

In mature economies, the services sector comprises a large and growing share of gross domestic product. Service sector firms comprise a small but fast growing segment of private sector R&D (Miles 2005). Industries in this sector include financial services; professional, scientific and technical services; and health care services. Service sector firms’ R&D efforts have been situated as "services sciences,"[33] at the intersection of IT and business processes, while also involving management, computational, social science, and cognitive science disciplines. Thus, for the most part, costs may be viewed as being similar to the software industry. The high labour mobility experience in certain services R&D sectors and countries may result in relatively high overhead costs associated with personnel recruitment and retention and IP protection (for example, legal costs associated with non-compete and confidentiality agreements).

It has been debated the extent to which many innovations can be traced to R&D efforts of small versus start-up firms (Baumol 2002; Teather 1988). Nevertheless, it is clear that the costs of R&D for start-up firms can be high relative to their size. Many small firms are finding that the availability of open sourced software and content has reduced some of the cost of starting up a new R&D intensive enterprise. As a result, less venture capital and other types of early stage support are needed to maintain new firm operations.[34]

4.1.8 Public policy

Fiscal policy and research policy have a great impact on research costs. There are several ways for a policy maker to influence private R&D: issuing R&D contract, granting subsidies and allowing tax credits. As far as R&D contracts with the private sector are concerned, there are several channels to affect private R&D: lowering the cost of R&D, signalling future demand, improvement of the chances for success and overcoming start-up costs. However, much of the evidence depends on US studies and many studies indicate substitution of public for private R&D instead of being additional (David et al. 2000). On several levels of aggregation (micro, meso, and aggregate) different authors arrive at different conclusions: on the aggregate level, there appears to be an impact on R&D input prices contributing to complementary movements in the private and public components of R&D expenditures (David et al., 2000). The firm level studies point at complementarities, especially in US and Finland, industry level studies also give indication that complementarities are prevalent.

Despite these partly inconclusive results there, numerous papers present real effects on the cost of research of tax credits as a RTD policy instrument. Hall and Van Reenen (2000), consider the tax treatment of R&D across 25 countries and draw the conclusion that the user cost of R&D is definitely impacted. R&D tax credits produce more R&D spending with an elasticity of around 1.0. The tax system affects the cost of an additional unit of R&D in two ways: the revenues earned from the investment and the reduction of the cost of the investment by depreciation allowances and tax credits. There are huge differences in the national regimes of R&D tax credits and subsidies and these differences changed over time as well. It appears to Hall and Van Reenen (2000) that tax treatment becomes more lenient, and that countries turn away from direct R&D grants.

In certain cases tax policy can be decisive factor. If the social rate of return is (assumed to be) higher than the private rate of return public policy might be justified and tax credits or R&D subsidies are then the main instruments. In a recent brochure of a Belgian research centre it is argued that starting a R&D project in France is more than 40% cheaper than starting it in Germany (Agoria 2009). Furthermore location, endowments and cooperation and accessibility of related (complementary) knowledge impacts the appropriation cost of knowledge impacting the R&D expenditure and or the price of R&D.

[33] See for example, IBM Almaden Services Research http://www.almaden.ibm.com/asr/

[34] See for example, Is venture capital no longer relevant? Funding startups in a new financial environment. http://www.cherry.gatech.edu/Forum/

For 20 industries in 9 countries over 1979-1997, Bloom et al. (2002) conclude that fiscal provisions for R&D matter. Among the countries, the differences in the tax system create difference in the user cost of R&D. The short run effect is not large bur the long run effect is quite substantial. They also touch upon the question whether or not tax credit are desirable. The answer they give is three pronged: there are administrative cost attached to the system of tax credits, there are many perverse incentive introduced by tax credits and last but not least in a world of international spillovers a country might be better off by free riding on R&D efforts of others, rather than subsidizing domestic R&D.

Lokshin and Mohnen (2007) conclude that R&D capital accumulation of a firm is responsive to its user cost. In an econometric model on a firm-level sample covering 1996-2004 for the Netherlands they found that, R&D is responsive to its user cost. The short-run elasticity they obtained is about 0.3 with a long-run elasticity of 0.7, while the effect is the largest for smallest firms and is smaller for the larger firms. Their overall conclusion is that the program of R&D incentives in the Netherlands has been effective in reducing the user cost of R&D and therefore has been successful in stimulating firm R&D capital formation.

Although there is no overwhelming evidence that public R&D causes additional or complementary private R&D, it is clear that the effect depends on the channel and instruments used by the policy maker. However, the effects of RTD policy in general on R&D costs are too complicated to come up with clear statements about their nature (Cox and Gagliardi 2009). The location of public (funded) research institutes also plays a role in the location of Foreign Direct Investment Decisions but it difficult to address this in terms of considerations of cost.

The unifying principle of the single market of the European Union is the free movement of labour, capital, goods and services, delivering the free circulation of knowledge in the EU. Important players on the large single European market are the knowledge intensive enterprises (large and small alike) which are considered by the European Commission (EC) as important carriers of innovation, employment as well as social and local integration in Europe. The EU Framework and other EU, National and Regional programmes support research and impact the cost of research at the same time. The impacts for the different sectors of economic activity can be quite different because the priorities chosen by the EC in the current FP6 and 7. These programmes target in the first place the R&D intensive industries as pharmaceuticals, radio, TV and communication equipment and services.

In conclusion, there exist several instruments to stimulate R&D, their effect depends on the environment in which the research is conducted, especially the industry and the size of the firm are relevant contextual factors. It seems that a tax incentive to stimulate R&D is a useful instrument, more than direct R&D grants. A question could be how sensible firms are to these regulations with respect to their location of research activities and or production. However, from the (short) literature overview mentioned here many aspects have been studied already.

4.1.9 Specific cost drivers for Public Research Organisations

There is some literature which deals with specifics of PROs. One of the important trend concerns the recent reforms aimed at promoting the efficiency of the public investment, in presence of rising costs and diminishing resources. Cost efficiency in PROs could be mainly intended in the sense of mechanisms of coordination that “maximizes social welfare”. In this view it is relevant to look at the relation between costs and performance, intended as research productivity, ratio between scientific output and R&D expenditures, through a range of indicators of scientific outputs, such as those used in evaluation activities (publications, patents, software, spin offs).

Other relevant trends are:

- The relation between internal decision making processes and the evolutionary institutional change, mainly the changing relation between State and scientific community, has been quickened in recent years, mainly through a change in the sources of funding (IPRs, research contracts and services).
- The openness of research, which is the rule for PROs, has been enhanced by a growth of international collaborations and networks (international programmes as source of funds; Lisbon goals).
- Excellence has become a relevant goal in itself.

The analytical framework for PROs is basically the same as for industrial firms. General common factors are the distinction between internal and external to the organisations factors impacting on costs of research for PROs, the attention to the interrelations among internal and external forces and to the dynamics, i.e. the relevance of the evolutionary institutional change.

Specific aspects related to the analytical frame work for PROs are the following:

- the R&D activity represents "the general mission" of PROs,
- the output of the research activity is knowledge that can take the form of transferable or not transferable type,
- the internal factors relate to PROs characteristics concern their degree of autonomy, mainly in terms of source of funds, and their mission, in terms of typology of research activity (basic versus applied),
- supply and demand factors are mainly related to human resources mobility, more than education quality and availability,
- local and global environment concern mainly collaborations and geographical proximity to firms.

As to external factors, market plays a weaker role as in industrial firms although the importance of markets has grown in the last decade. Market-based mechanisms are mainly relevant for specific outcomes and activities whereas PROs have different markets since they have different kinds of output: research product, services, consulting activities, etc. In general, there is a complex interaction between market elements and the regulatory power of governments. Elements of competition, such as individual/organisation responsibility and freedom of choice are introduced into the system, but government regulation and financing still remain important coordination mechanisms.

The drive to commercialization doesn't obscure the fact that for many centres the primary goal remains the public interest, including R&D for public goods and the provision of scientific advice to government. The growth of competition (for funding and for qualified human resources) into a contestable market- by Universities and private organisations- allows mainly for potentially higher accountability and transparency.

The introduction of quasi-market has three dimensions with a different relevance among centres and within PROs:

- growth of competition between research activity providers,
- privatization of PROs or of some aspects of public institutions,
- turning PROs into economic autonomy entities, enhancing their responsiveness and articulation to the supply and demand of factors and products.

The government requires that PROs behave in certain way or it gives incentives/constraints to PROs behaviour for safeguarding public interest. PROs are evacuate, transformed or redirected by non-market forces. Resources with public commitment for medium-long term are an important component of PROs funding.

As to internal factors, PROs have some discretionary range in choosing how to comply with State requirements. They don't rely on rational pursuit of corporate interest; the resource allocation is not directed by market mechanism consideration; supply function doesn't reflect opportunity cost of inputs. Instead internal decisions reflect the influence of a combination of different agents/units with different interests: governing boards, administrators, researchers, stakeholders (when present). The resulting decisions are the outcome of bargaining processes where some units/individuals are in position to influence decisions on goals, funding and internal resources allocation.

PROs R&D prices don't reflect true costs, given the presence of government funding and subsidies. A full cost accounting system is not existent in all organisations and varies between types of PRO and country.[35] While in countries such as UK, the Netherlands, Germany, and Austria, cost accounting is largely diffused also within PRO, in France, Spain, and Italy it is less diffused. Hence, the role of price for allocation, signalling and rationing varies considerable within Europe.

Based on the above mentioned arguments provided in the last nine sub-chapters we propose the following three specific hypotheses for companies and PROs which - amongst others - should be tested by our empirical study:

Hypothesis 1: The productivity of R&D is characterised by a trade-off between cost and quality. Thus, an organisation could either strive for excellent research at higher costs or routinised, less complex research with lower costs.

Hypothesis 2: The technological complexity drives market concentration. In such markets strategic factors are important in R&D decision making. With less technological complexity product markets are more contestable and cost factors are more important.

Hypothesis 3: Collaboration and location (e.g. spillover) are important to manage and contain the costs of research.

35 The members of the expert group stressed particular that the introduction of (full) cost accounting systems is an important driver for PRO (and universities).

4.2 Drivers of costs of research: Findings from the empirical study

4.2.1 Companies

In the COST survey we have asked for the importance of a number of drivers for research cost which largely cover the factors described in the previous chapter.

The drivers of costs of R&D consist of cost inhibitors (reducing costs) as well as costs triggers which boost the cost of R&D. However the final (or average) effect of the inhibitors and triggers lead to a positive cost increase effect on R&D.[36] **Cost inhibitors** (factors which reduce costs) are found among factors as aligning R&D with business strategies, joining collaborative R&D projects and technological efficiency of the R&D process[37]. Table 16 exhibits these cost inhibitors as factors that have scores below the neutral score of 3.00 for both periods. The questions were phrased in a 5-point Likert scale ranging from 1 (very important cost reductions) to 5 (very important cost increases).

Table 16: Drivers of the cost of R&D in companies (Importance from 1 (= very important cost reductions) – 5 (very important cost increases)).

Drivers of cost of R&D (Companies)	Currently N = 83	over five years N = 75	Trend[38]	Extra-polation[39]
Availability of qualified researchers	3.36	3.51	4.46	3.67
Regulation of labour market for scientists	2.99	3.06	2.34	3.13
Regulation of product market	3.35	3.44	2.69	3.53
Complexity of the R&D process	3.63	3.80	4.68	3.98
Duration of the R&D process	3.40	3.31	-2.65	3.22
Scale of R&D projects	3.36	3.42	1.79	3.48
Location of R&D projects	3.10	3.00	-3.23	2.90
Technological efficiency in the R&D process	2.65	2.60	-1.89	2.55
Cost of patenting	3.08	3.23	4.87	3.39
Litigation or the threat of litigation	3.03	3.17	4.62	3.32
Environmental legislation	3.47	3.78	8.93	4.12
Joining collaborative R&D projects	2.59	2.65	2.32	2.71
Aligning R&D opportunities with business strategies (roadmapping)	2.66	2.64	-0.75	2.62
Average	3.13	3.20		

Source: EU Survey on Cost of Research (2011)

36 This conclusion is valid as far as all drivers of cost mentioned in the table have equal impact on R&D costs.

37 Technological efficiency of the R&D process measures the output of the R&D process in relation to the kind and size of the technologies used in the R&D process.

38 The column with heading ‘Trend’ shows the rate of growth in five years of the importance-score of each single driver. For example, for the driver ‘Availability of qualified researchers’ the value 4.46 is obtained as: (3.51 - 3.36)/3.36*100.

39 The extrapolation is the simple prediction of the Trend score for the next five years (thus, ten tears after the current situation). For the driver ‘Availability of qualified researchers’ the extrapolation value is obtain as: 3.51*(1+0.046).

Cost triggers are more numerous and three stand out: complexity of the R&D process, environmental legislation and duration of R&D projects. The strongest trend are found in environmental legislation (+9%), cost of patenting (+4.9%) and complexity (+4.6%).

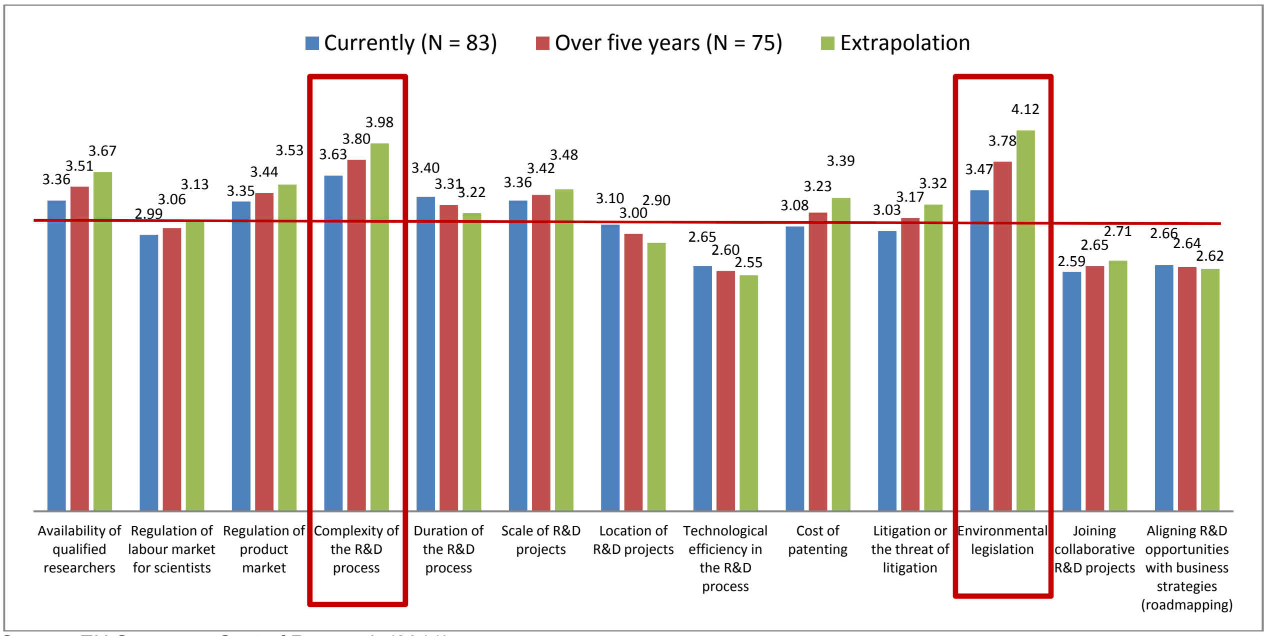
It is somehow surprising to see reported a 'cost increasing trend' for the 'cost of patenting', since there are many efforts, at least in Europe, to reduce the cost of patenting. This probably refers to increasing patent applications and not to the expectations of costs for a single patent.

Location of R&D projects as well as labour market regulation are more or less cost neutral, while in the literature there is much attention and importance given to both phenomena as source of decreasing cost (see above). As we already saw regarding the relatively small R&D wage differences between 'main' and 'dynamic regions' the location of R&D is not a major determinant for the cost of R&D.

A factors analysis using a varimax rotation for each period (current and over 5 years) shows that the most important factors for both periods explaining 30% of the variance of the whole group of drivers' variables, is related the three cost inhibitors mentioned above (technological efficiency, collaborative R&D projects and alignment of R&D and business strategies). Differently, cost triggers are not identifiable as a homogenous group.

Figure 35 exhibits a graphical representation of the data in Table 16.

Figure 35: Drivers of cost of R&D in companies, (Importance from 1 (= very important cost reductions) – 5 (very important cost increases)).



Source: EU Survey on Cost of Research (2011)

One can ask the question what the relative importance of cost drivers are for both periods: Is the significance and relative composition of the set of costs drivers now and over 5 years the same, or is it different?

Investigating this question we found that a regression of the (mean values) of the future important cost drivers on the current (mean values) of cost drivers is as follows:

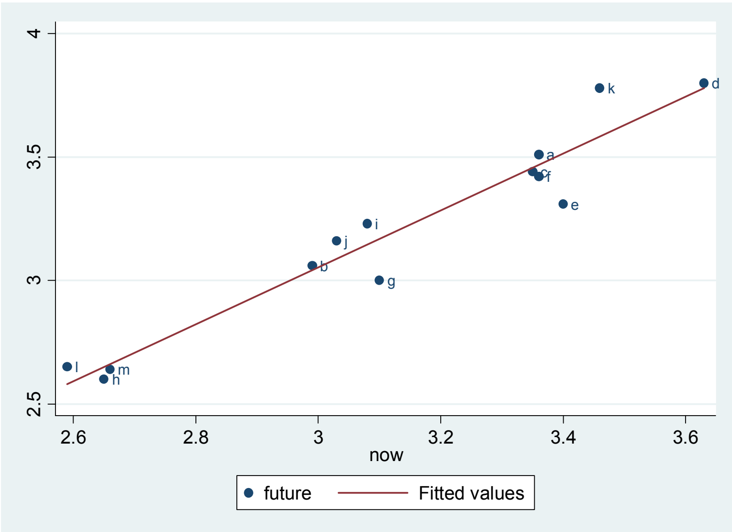
$$(1) \quad MQ4(+5) = -0.40 + 1.15 * MQ4$$

The interpretation is that on average (measured by means) the intensity of cost drivers tend to increase over a period of five years by 1.75%, or 0.35% annually, when the current score is equal to 3, that is the neutral benchmark: it means that if the average driver is equal to three now it will became equal to 3.052 after five years.

If we use this relation to extrapolate (forecast) the intensity of the cost drivers five years later, it turns out that complexity of R&D process gets the highest growth (4.60% of its score) and environmental regulation follows with 4.55%.

Figure 36, finally, shows that only three drivers comply less with the generic relation (1): location of R&D projects (Question 4g), duration of R&D project (Question 4e) and environmental regulation (Question 4k).

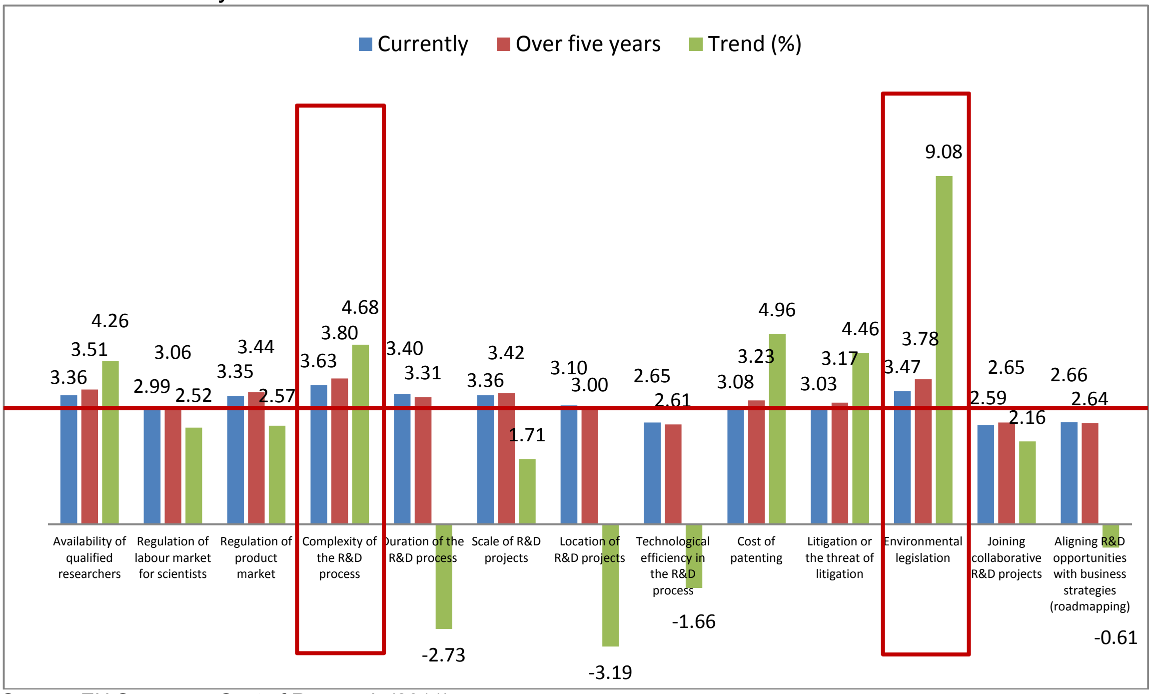
Figure 36: Relation between future and current driver scores (scale: Importance from 1 (= very important cost reductions) – 5 (very important cost increases)).



The characters correspond with the list of drivers in the company survey questionnaire
Source: EU Survey on Cost of Research (2011)

We found minor to modest differences of the drivers when taking into account the sector. Figure 37 shows the importance of drivers of R&D costs. Generally speaking, for all sectors complexity of R&D process is the most important driver of cost increase both in the present and in the past; nevertheless, while for Pharmaceuticals the second most important cost trigger (both in the past and in the future) is the regulation of product market, Automotive follow the average result showing that is environmental regulation the second most important factor favouring cost increase (for past and future). The fact that regulations are important cost drivers in the pharmaceutical industry was also found in literature and was described in chapter 4.1.5. Differently, for ICT in the past the second trigger was the scale of R&D projects, and in the future environmental regulation; for other sectors, finally, in the past the second driver of cost increase was the scale of R&D projects, and in the future, even in this case, environmental regulation. As for cost inhibitors, all sectors show that technological efficiency in the R&D process, collaborative R&D and aligning R&D opportunities with business strategies are the most important; nevertheless, for ICT the collaborative R&D is in the first position, while for automotive aligning R&D with business seem comparatively more relevant.

Figure 37: Drivers of R&D costs, (Importance from 1 (= very important cost reductions) – 5 (very important cost increases)). Trend (%) is the percentage change of the score between now and over five years.



Source: EU Survey on Cost of Research (2011)

There are only minor differences regarding the drivers when taking into account the nationality of ownership (EU, Non-EU) (see Table 17). However, of interest is that companies expect that almost all drivers will have a bigger influence in the future in Non-EU companies (the only exception is cost of patenting and environmental legislation).

Table 17: Drivers of R&D costs: companies from EU versus Non-EU countries (Importance from 1 (= very important cost reductions) – 5 (very important cost increases)).

Drivers		**EU** (N = 89)	**Non-EU** (N = 14)
Availability of qualified researchers	Now	3.35	3.45
	In five years	3.49	3.63
Regulation of the labour market for scientists	Now	3.02	2.78
	In five years	3.07	2.99
Regulation of the product market	Now	3.34	3.43
	In five years	3.42	3.58
Complexity of the R&D process	Now	3.66	3.49
	In five years	3.80	3.81
Duration of R&D projects	Now	3.43	3.25
	In five years	3.32	3.24
Scale of R&D projects	Now	3.35	3.44
	In five years	3.39	3.59
Location of R&D projects	Now	3.10	3.09
	In five years	2.98	3.14
Technological efficiency in the R&D process	Now	2.67	2.50

	In five years	2.61	2.56
Cost of patenting	Now	3.10	2.96
	In five years	3.25	3.12
Litigation or threat of litigation	Now	3.02	3.09
	In five years	3.14	3.33
Environmental legislation/regulation	Now	3.50	3.30
	In five years	3.82	3.57
Possibilities of joining collaborative R&D projects	Now	2.59	2.63
	In five years	2.64	2.71
Aligning R&D opportunities with business strategies	Now	2.64	2.81
	In five years	2.58	3.01

Source: EU Survey on Cost of Research (2011)

A comparison of the drivers considering the size reveals (not disclosed here) that the larger firms less often stressed the importance of location as cost driver but generally considered all other drivers as having a stronger impact than smaller firms, - both now but also in the future.

Increased researcher mobility across countries suggests that the international competitions for researchers has increased and that this must have had an effect on wages and probably on other R&D cost components, for example, increased activity in conferences, research visits, research related travels, etc.

As described, **environmental regulation** is the most dominant cost driver for R&D. This adds not only to the cost of individual research projects, it also requires new test and certification processes to be developed for each new technology. Associated investment needs to be made in the certification infrastructure supporting new products. Ostensibly, the fact that adaption of organisational processes or facilities to newly introduced regulations is a source of costs for R&D seems very obvious which is in line with findings from the literature. Jaffe and Palmer (1997), for instance, estimated the relationship between total R&D expenditures (or the number of successful patent applications) and pollution abatement costs (a proxy for the stringency of environmental regulation). They found a positive link with R&D expenditures (an increase of 0.15% in R&D expenditures for a pollution abatement cost increase of 1%).

However, when regarding the consequences of such investments these can be seen as a source of innovation as well. Regarding the hypothesis that the cost of implementing environmental regulations may be expected to be significantly reduced by low-cost process and other innovations carried out by regulated firms. This hypothesis has been popularized by Porter (1991), who argued that *"strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it."*[40]

Regulatory pressures may translate into a competitive advantage for businesses that do invest in adapting their products to regulatory requirements or indeed chose to take the lead in creating new regulations, standards and platforms. The electric appliances manufacturer

[40] The Porter Hypothesis has been examined widely in the literature with mixed findings. Ambec et al. (2011), for instance, analyzed 28 studies on the Porter Hypothesis. They state that the theoretical arguments that could justify the PH have become more solid. And, on the empirical side, on the one hand, the evidence about the "weak" version of the hypothesis (stricter regulation leads to more innovation) seems them to be fairly well established. On the other hand, the empirical evidence on the strong version (stricter regulation enhances business performance) is regarded as mixed, with more recent studies providing more supportive results. The authors refer also to the similar conclusions of Brännlund and Lundgren (2009). Most authors come to the conclusion that results are very context-specific.

FAGOR sees the effect of energy efficiency regulation and the fact that now up to 60% of research investment are dedicated to this focus as translating into a competitive advantage for those European manufacturers who developed a strength in this area, a view echoed by Bosch that dedicates some 45% of its research budgets to strengthening the company's ecological orientation.

The case studies provide ample evidence about how different factors affect research costs in different environments.[41] **Technological, market, and policy factors** are identified by interviewees as key cost drivers. One of the most prevalent cost drivers in the company survey was the **increasing complexity of products**, which in turn is partly driven by customer demand for better performance of products, e.g. in respect to flexibility, energy-efficiency, safety, etc., that have research cost effect. The case studies further elucidate what is behind this response. Several interviewees indicate that their products incorporate and integrate a larger number of diverse features and technologies (stressed for instance by DSM, Motorola and Texas Instruments), have extensive integration requirements with others along with global supply chain (e.g. Bosch), and feature ever more customization (e.g. Homag). The Medtronic case presents the example of the pacemaker which has incorporated 195 US patents since 2001. In addition, some of the case studies indicate that the **sheer number of products** is on the rise. Rapid technological change is another cost driver as Texas Instruments pointed out.

Increasing Complexity: A Major Driver of Costs

The increasing complexity of products is important factor in understanding R&D costs and productivity. Because of increasing product complexity, one cannot look at simple relationships between R&D outputs and inputs in isolation. Complexity encompasses several dimensions including customer factors, product diversity, integration needs, open innovation issues, and support infrastructure. These dimensions are exemplified as follows:

- Customer driven: Complexity of software systems has significantly increased because their customers' problems are more complex.
- Diverse products: Rhodia manages a range of products in cosmetics, automotive, and chemical industries, each with different requirements for R&D investment scales and cycles.
- Greater integration: Bracco Imaging deals with "integrated product solutions" rather than discrete products and must attend to process efficiency, environmental sustainability, pre-clinical and clinical safety, and concomitant training requirements. Bosch's products integrate many diverse components and subassemblies, requiring systems concerned with materials science and manufacturing engineering to incorporate these components and subassemblies well and at increasingly high levels of quality.
- Open innovation: The adoption of open innovation strategies by GDF Suez, DSM, and Rhodia adds to the complexity of R&D choices and projects in issues such as locating R&D solutions even outside the companies' main industry and in efforts to combine R&D from external partners.
- Support services: Programmable products at Texas Instruments address an increasing level of capability, requiring that in-house software be written to support these products.

A major driver for firms is the **shortening of product development cycles**, nowadays companies have to spend more to develop products in shorter times, though, firms do not necessarily earn proportionally more with new products. There is a possibility that sustainability issues will outweigh novelty as a consumer or industrial purchasing criterion and modify the 15 year emphasis on speed to market and concurrent engineering. Designs with a longer design shelf-life could be perceived as more desirable because of the energy efficiency

[41] See also chapter 6 where further findings from the case studies regarding drivers are used to construct scenarios.

of reduced production levels. The R&D cost implications of designing for product longevity will depend on how the objective can be achieved. This has important implications for business strategy as well as R&D project management and costs. It also has policy implications in so far as multiple policy objectives (such as environment and economy) can be addressed simultaneously.

Rhodia: shortened and diverse product cycles.
Rhodia is a French chemical company that has distinctive R&D challenges in addressing product life cycles. The scale of the company's R&D investment varies according to the length of a particular product's life cycle, ranging from over 6% of turnover for some R&D intensive products to less than 1% in others, within a total average of below 2% for the whole group. For example, product life cycles are very short in the cosmetic industry as there is a need to ensure that 'trendy' products reach the market in time. In contrast, regulatory requirements drive automotive catalysis innovation and long-time-to-market for automotive tires produces greater incremental innovation. Chemicals such as polyamide rely on standard innovation practices in the development of new applications. Each type and cycle of innovation is associated with different time frames for investment decisions that are more significant than basic R&D cost factors alone. Moreover, Rhodia finds that product life cycles are increasingly becoming shorter requiring more frequent demonstration and pilot phases, and customization drivers are leading to a decrease in unit sizes.

On the market side, the importance of **customer-driven innovation** over technology-driven innovation is underscored in the Philips case. High **quality expectations** of customers over the life of the product also drive research costs as noted in the Bosch case. Greater competition from low cost companies mostly in Asia is a common theme, even as Asian markets offer enhanced growth potential. Bosch targets China and South Korea and Philips reports that 40% of its growth will come from Asia. DSM views increased presence in emerging economies as one of its three strategic pillars, along with innovation and operational excellence. Some markets are consolidating, which also tightens competition (e.g. as stressed by Tellabs) whereas other markets (notably the energy sector) are expanding and including more competitors (such as GDF Suez). Several cases stressed the importance of shorter time-to-market as a significant future trend. And although regulation is considered a cost driver for higher research costs, as in the pharmaceuticals industry (Astra Zeneca, Medtronic) and the energy industry (GDF Suez), at the same time, interviewees made mention of the importance of sustainability policies in creating new market opportunities. Bosch expects that 45% of its R&D spending will concern green product offerings.

4.2.2 Public Research Organisations

Drivers of cost of R&D are exhibited in Table 18 (and
Figure 38) below. The drivers of cost of R&D for PROs are all positive, cost increasing drivers (not one single driver has a value below the cost neutral 3.0 level) and also their trends are positive.

Cost inhibitors as found in companies are not present here. It might mean that we did not ask their reaction to appropriate pre-defined cost drivers. But, this seems unlikely, since no additional drivers were mentioned in the 'open' question on cost drivers (question 4n). It might also mean that PROs are not aware of instruments that inhibit costs[42]. That means that there are (almost) no consistent cost inhibitors for PROs, which is quite remarkable. Among the

42 The likelihood that the questions in Question 4 Drivers of cost of R&D in the survey does not adequately cover the possible drivers at work is small because there were almost no answers the open question on cost drivers (i.e. question 4n).

most important positive cost drivers are complexity of the R&D process and the cost of applying for research grants. Regarding the trend in the importance for increasing cost (the difference in importance between the current and future situation, see the columns in Table 18) the increase in importance of the 'Cost of communicating and reporting results' is by far the strongest.

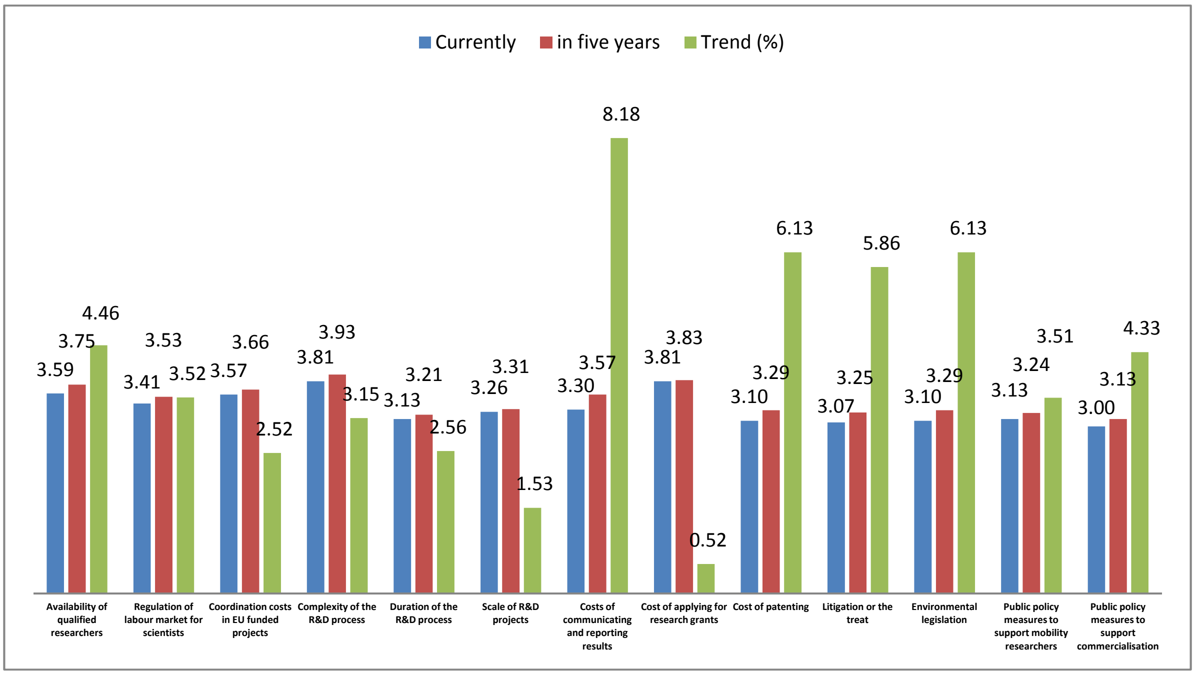
One would assume that all the policy related drivers help to reduce costs, but as perceived by the respondents, they did not. Although it is unlikely that for instance the coordination costs are larger than the value of the subsidy received, costs such as for applications, reporting and coordination are seen as 'cost-increasing factors', especially for the next five years. The same holds for the 'cost of applying for research grant' where respondents had increasing administrative cost in mind which reduces the net benefit of this type of research projects.

Table 18: Drivers of costs of R&D (Importance from 1 (= very important cost reductions) – 5 (very important cost increases)).

Drivers of the Cost of R&D in PROs	**Currently** N = 31	**over five years** N = 29	**Trend**
Availability of qualified researchers	3.59	3.75	4.46
Regulation of labour market for scientists	3.41	3.53	3.52
Coordination costs in EU funded projects	3.57	3.66	2.52
Complexity of the R&D process	3.81	3.93	3.15
Duration of the R&D process	3.13	3.21	2.56
Scale of R&D projects	3.26	3.31	1.53
Costs of communicating and reporting results	3.30	3.57	8.18
Cost of applying for research grants	3.81	3.83	0.52
Cost of patenting	3.10	3.29	6.13
Litigation or the treat	3.07	3.25	5.86
Environmental legislation	3.10	3.29	6.13
Public policy measures to support mobility researchers	3.13	3.24	3.51
Public policy measures to support commercialisation	3.00	3.13	0.13
Average	3.33	3.46	0.13

Source: EU Survey on Cost of Research (2011)

Figure 38: Drivers of costs of R&D (Importance from 1 (= very important cost reductions) – 5 (very important cost increases)).



Source: EU Survey on Cost of Research (2011)

Quite remarkable is also that public policy measures to **support mobility of researchers** is a light cost driver and will become more significant a driver in the coming five years according the respondents. Only recently mobility of the highly skilled in EU27 got more attention of policy makers. The EU Blue Card has been implemented in May 2009 and does only provide mobile knowledge workers with outlook for a short term and there is no level playing field. Therefore there are many hurdles (immigration rulings, tax systems, fragmented information etc.) for mobility within EU. Especially PROs are confronted with the tendency to lose their most talented R&D worker to companies, while the visibility of EU initiative to promote free movement of workers still seems to be very poor (see e.g. Crespi et al. 2007). For these reasons it is possible that the labour market position of PROs deteriorates and this implies concern for the future and it implies higher cost to attract talented researchers.

These drivers of costs for R&D, especially the **complexity of the R&D process**, the cost of **applying for research grants** and **coordination costs in EU funded projects** as well as the concern about excellent future **human capital** of PROs are **strongly emphasized through the results of the case studies**:

Global competition for top scientists as challenge for PROs human capital

Most of the PROs mentioned the importance of qualified researchers, which depending on market prices can become a significant cost driver for those of the PROs which are not limited to salary plans by the government. There is a global competition for top scientists and PROs have only limited scope to pay the market rates. Competition in the global market for scientific competences is heightening and in order to attract key staff, an organisation like INRA would need to pay market rates. INRA has on a few occasions recruited world leading scientists and is paying market rates for these for a determined period of time, but there is very limited scope to extend this (it is currently in the order of 20 out of 8000+ staff). This is seen as a special investment as argued by managers of INRA. SINTEF also referred to international mobility as a key driver for research costs.

Coordination costs in EU funded projects are also mentioned by most of the PROs as relevant cost drivers. On the one hand rising administration is mentioned as a source of rising costs on the other hand the internal co-financing that occurs with the increasing number of their EU projects. In addition, the managers of one PRO, KIT, pointed out the problem that the EU funds only a small amount of infrastructure.

Concerning rising administration and regulation, the CEO of the Italian ELETTRA also pointed out a **new regulation of the public administration** in Italy: "*But the main driver of increasing costs is of a different nature and is represented by the administrative regulation and its frequent changes. In particular the recent regulation for public research organisation has brought a higher burden of bureaucracy, i.e. more constraints, control, registration and documentation for each daily activity (with a negative effect on labour productivity) and asked for more administrative personnel."* The interviewed DLR manager, for instance, stated: *"Administration costs are increasing as well. DLR receives public funds which is also associated with increasing accountability costs ("demonstrating what we have done with this money"). Other regulations, such as e.g. environmental requirements are increasing, too."*

A major trend for the research costs of MRI (Moredun Research Institute based in Penicuik in Midlothian, Scotland) is the cost of conducting animal trials. The director of Genecom Ltd, the Moredun Research Institute's research and exploitation subsidiary stated: "*The general cost of maintaining its own farms and animals has increased faster than inflation in recent years. Further, the increased regulation and oversight with regard to the welfare and treatment of animals has increased costs of research significantly."* MRI was a major contributor to the creation of legislation and monitoring procedures but now finds itself having to increase its own quality and welfare assurance standards to one that is always exemplary in the agricultural sector.

CSTB as a PRO working in the sector of low tech industry points out that low tech industry must still 'catch up' to reach the level of R&D expenses of other industries, which increases R&D costs, and so does interdisciplinary working. The R&D director of CSTB himself told us that cost increases are associated with developments regarding the public mission of the CSTB: *"The centre's role is to contribute to an understanding and the detailed management of construction-related issues for a large diversity of public policy domains and responsibilities from safety and health to energy and environment, social and economic dimensions of the construction industry all the way to its preparedness for digital economy requirements. As a result of this regulatory pressure, any new product, such as for instance new concrete, needs to be tested in all these respects. This regulatory pressure on the research costs associated with each new construction application also leads to considerable constraints on CSTB's cost management approach and ultimate profitability of the portfolio of activities, since it necessitates a greater emphasis on applied research."* He expressed the view, however, that the European Commission would play a key role in decreasing this regulatory burden by helping to align regulations in different European countries analogous to the role that the Schengen agreement played with regard to border controls.

Additionally, The R&D director of CSTB identified a fairly recent emphasis on R&D and innovation in the construction sector as a further driver for a rise in research costs that he expects to continue into the future. The current construction sector investment in R&D in France amounts to only 0.3% of the GDP generated by the sector and this is ten times the amount of construction sector R&D investment across Europe as a whole.

Fulfilling public mission in a world of complex research

Some of the PROs are arguing that the change in nature of research and technological development is driven by the convergence of technologies with strong role of ICTs and modelling work, which, in turn considerably increased the cost base. The rising complexity of the research process is due to the consideration of environmental, regulatory, and safety factors.

The French agricultural research centre INRA, for instance, has had to make significant investment in ICT infrastructure and skills, since bioinformatics are of growing importance for the whole area of agricultural research. The main driver behind rising costs relates to the nature of the research undertaken. As a result of the advent of genomics and bioinformatics and climate change\eco system modeling, the nature of much of the research undertaken – research that a centre like INRA needs to be involved in to remain at the leading edge and to fulfil its public good mission – dictates investments in the corresponding facilities and devices" as was argued again by managers of INRA.

The president of INRIM, the Italian national metrology research institute stated: "The main driver of cost comes from the enlargement of activity due to new demand, such as environment, health, energy measurements, and demand of more improved measurement. The growing need for reliable, comparable measurements has led to strong growth in metrology in chemistry and biosciences: in the INRIM laboratories measurement procedures are being finalised for measuring atmospheric pollutants, analyses are being carried out on environmental, food and biological matrices, and reference standards are being set for weather monitoring. There is a European coordination of large projects of research on the new fields. The participation to these European projects is necessary and helps to sustain the enlargement of research activity and the related cost.

IMT (Institute of Microstructure Technology at the Karlsruhe Institute of Technology) managers argued: *"As (frontrunner) R&D institute we are forced to do always new things. Our challenge is to be interesting for scientists to come to us and use our facilities and to be better than other Helmholtz institutes in order to get internal program funding every five years. We are in the scientific competition."*

Similarly, DLR, IST (Italian National Institute for Research on Cancer), SINTEF and VTT (multi-disciplinary research institutes in Norway) make reference to the significant investment in research infrastructures and facilities, which is often provided out of public funds, in order to meet the scientific goals and fulfil public missions.

In addition, the technological S-curve explains also the increasing research costs in some areas. Within aeronautics, e.g., the interviewed manager of DLR argues: *"The main understandings of aviation are clear. Now the steps of technology improvement are getting smaller and smaller. And this increases costs".*

The importance of international mobility as a cost driver (which was a result of the survey) was affirmed by the case study of SINTEF, for which this is seen as a key driver, particularly.

Also the low importance of patent costs as drivers is approved and even strengthened by the case studies: PROs do not patent much and thus the **costs for patenting** do not present a relevant cost category for them.

However, there were also revealed additional cost drivers by the case studies especially for PROs which maintain large experimental devices. For these PROs main cost drivers are **energy and equipment**. Managers of IBA, e.g., argued: *"Costs of energy and raw materials have increased during the last years. This becomes a problem for public research organisations more and more because the funds do not increase in the same way. At the opposite, expenses are limited by the amount of the funds of the last year."* In addition, personnel costs have increased (more than in the western part of Germany) due to the fact that IBA is located in the east of Germany.

Large-scale research facilities

Pioneering scientific research could simply not take place without large-scale facilities. It is only with large-scale, unique research facilities that one can make certain material visible or carry out pioneering experiments. Linking various different facilities can increase the scope of research enormously. By linking facilities to a large infrastructure network, researchers can bring about an exponential increase in the number of observations and experiments that are carried out. The network generates far more research results than could ever be done by all the individual groups together. The value of linking up research data is much greater than the sum of the parts.

Large-scale research facilities are not only of crucial importance for acquiring new knowledge but have also contributed to a more efficient way of working in the world of science. Large-scale infrastructures are sometimes necessary in order to achieve the set scientific goals within a given time. Shortening the time needed to carry out research is not only advantageous from the financial point of view but can also have major scientific and social advantages.

The role and added value of large-scale research facilities need to be considered against the background of the scaling up and concentration of research. The development of large-scale research facilities and technologies has made a major contribution to this. Such facilities ensure, on the one hand, that the research is centralised around unique instruments and, on the other hand, that increases of scale are achieved by combining and integrating complex, linked research facilities. The use of large-scale facilities and the scaling up of research is to a great extent associated with the increased integration of research.[43]

[43] See in this respect also a recent study by Technopolis on large infrastructure: Technopolis Group (2011): The role and added value of large-scale research facilities, 10 February 2011, www.technopolis-group.com.

5 Organisational responses

5.1 Evidence from the literature

Strategy, management, organisation and the nature of the R&D process matters. Strategy and structure of the R&D process entails two choices: the type of research and how to organise it. The type of research can be quite general or specific this is called “basicness”. The way it is organised can be inside the firm or externally performed and this is called openness. R&D involves in this vision production and coordination costs, and the more basic R&D projects display higher production costs, while crossing organisational boundaries (more openness) brigs higher coordination costs. It is therefore that Cassiman and Valentini claim the more basic R&D programmes should be more open to reduce costs. That is why extramural research has grown twice as fast as intramural research (Lindner, 2003; Chesbrough, 2006).

New techniques and management approaches have been introduced in R&D because of business dynamics, continuing pressure to increase competitiveness, and the transfer of management methods from other functions, but not simply to reduce costs.

TQM, for instance, was introduced to R&D some years after it had become established in manufacturing management and other areas. Business process engineering was used at a corporate level rather than within R&D departments and had the effect in many companies of reducing business expenditures and closing R&D departments. It was not introduced as an efficiency device within R&D but as a way of focusing attention on the strategic justification of R&D budgets, or expenditures, and core competences.

There is much literature describing the different strategies and methods such asimproved methods of planning, control and financing R&D activity, collaborative networks, open innovation, research consortia, business simplification and decentralisation, etc. Each of the these factors individually and in combination may historically have influenced the costs of R&D. However, it is difficult to discern either isolated or cumulative effects, or trends. It is also difficult to predict the future effects of emergent trends on costs. Whether or not (any or all) management methods or business philosophies been responsible for increasing R&D costs is very unlikely.

What we know is that business managers strive to improve the competitiveness of their business. They use a combination of methods such as:

- diversification, acquisition or development of new business divisions or technology areas;
- improving service quality or business logistics;
- increasing efficiency via process innovation;
- increasing R&D expenditures to develop new products, improve existing products, or to introduce new products more quickly;
- Increase the effectiveness (i.e. how successful is the innovation process).

The various methods and approaches that have been used in R&D management are shown in the Table below. This summarises the changes that have occurred during the 1970s to 2010 as R&D management has progressed through 5 generations of management model (Rothwell 1992) and innovation management similarly through 5 generations of management model (Amidon 1996). The fifth generation model was predicted by Rothwell in 1992 and over

20 years it has materialised. It needed internet and ICTs to facilitate it. It is now termed the open-innovation approach after Chesbrough's popularisation of the trends (Chesbrough 2003).

Table 19: Overview of important R&D Management methods.

R&D management methods over 4 decades		
Past (approx 1970 to 2000)	Present (2000 -2010)	Future (2010 -)
Organisational structures Project selection, R&D portfolio management TQM BPR Core competences Concurrent engineering Laboratory notebooks KM Strategic exploitation of technology	Outsourcing Licensing-in IP Acquisition of high-tech SMEs Collaboration Strategic roadmapping IT support systems Open source International sites R&D as a business	Technology markets Knowledge modularity and plug-in connectivity Roadmaps R&D industry Foresighting Specialisation Virtualisation Image reputation intangibles Footballer salaries?
1st 2nd and 3rd generation R&D management models (linear technology push, linear market pull, iterative dialogue)	5th generation management models (open innovation and open R&D concepts)	5th generation model continues with enhancements Roadmapping applications progress from project planning and management information systems to strategic communication systems used across supply chains, and collaborative projects. R&D requirements are identified within such systems.

Source: own depiction.

The **first generation model** was a linear technology-push approach. Corporate (and government) labs pursued science in the hope that useful results would emerge. But the probability of success could be low; it was a risky approach. Tighter cost control within R&D activity would not necessarily have improved the probability of success. Cost control at the business level (or in government departments) was achieved by project selection and project termination decisions and this became more sophisticated via practical experience. It has been regarded not as cost control or cost reduction but instead as 'R&D effectiveness' and 'R&D performance measurement' or 'performance management'. These terms have been introduced partly because platforms of management capability have been successively introduced. The issues were not primarily to reduce costs within a given budget but to justify expenditures at a strategic level. TQM and business process engineering (BPE) focus on this objective. Kerssens van Drongelen et al (1999) have emphasised that methods of R&D performance measurement needed to be customised to individual business needs and preferences; there is no standard solution.

The **second generation model** (the customer contractor or market pull model) was a reaction to the linear technology push model and decentralised R&D budget decisions to business divisions. But this had the unintended consequence of stultifying more strategic or ambitious R&D objectives. The incentive to use R&D for this purpose was eliminated. Business divisions were only motivated to improve profitability via operational efficiency.

During the 1990s, whilst **third generation R&D management** (Saad et al., 1991) was diffusing (with consultancy encouragement) there was increasing recognition that business strategy needed to be more closely integrated with technology strategy (Coombs 1996). Hitherto it had been taken for granted that technology strategy was formulated to serve a business strategy. Partly this was because technology was perceived in a relatively narrow way (e.g. equipment procurement) until the concepts of capabilities and dynamic capabilities (Teece 1996) were better appreciated. Now it is understood by many companies (but not all) that without a technology strategy there can be no business strategy and that the two need to be synchronised and developed simultaneously. A technology strategy must be integrated with innovation strategy and R&D strategy. This is embedded in generic roadmapping frameworks (EIRMA 1997, Phaal et al 2004). Later it becomes incorporated, coincidentally, in the concept of business model innovation. Ganguly (1999) promoted the concept of "R&D as a business" as a natural development of about 15 years evolution managing R&D in a cost centre, then in a profit centre, then either as an internal contract R&D organisation with outside work, or with more independence, including management buyouts and spin off companies.

Similar motivations caused **restructuring of some PROs** including UK research associations; some of the latter converted 'successfully' (i.e. 'survived') as consultancy organisations, others were closed when government subsidies were reduced, others needed to become global operators in order to secure enough business but typically overall R&D effort declined. Universities in some countries have taken the place of corporate labs and even applied research and problem-solving capability and as a result 'mode 2' research (Gibbons et al. 1994) has proliferated (this modifies the concept of basic research).

Fourth and fifth generation models depend on increased dialogue between customers (or users) of R&D outputs and R&D (technology) suppliers. This has evolved in various ways and is being extensively researched as part of the open innovation phenomenon. There is now recognition and incentive for creative approaches to R&D management structures and systems. The concept of business model innovation has been introduced in the last 4 or 5 years. But it is not just the business models of R&D users (or knowledge exploiters) that might be innovated; it is also the business models of R&D performers, and in some cases user and performer roles might be combined in novel ways.

R&D is often now not justified as an internal expenditure within a corporate business. Where within a business supply chain (or knowledge chain) it is being performed and by whom is changing dramatically, by large firms as well as small firms and also by PROs. Specialist R&D organisations may be one kind of innovation intermediary (Howells 2006). Outsourcing (of manufacturing and IT systems and other functions) has expanded significantly. Businesses have simplified and restructured to become leaner enterprises (focusing on core competences). These trends mean that there are now different reasons for the resulting organisations to support R&D, and different ways for them to appropriate any benefits. But R&D itself can also be outsourced and this has included 'offshoring'. Overseas R&D investments have not only shifted from Europe and North America to India and China but also between Europe and North America.

But global corporations have pursued this level of internationalisation to an extent where they now think as a globally integrated organisation with R&D sites in different locations.

But global corporations have pursued this level of internationalisation to an extent where they now think as a globally integrated organisation with R&D sites in different locations, wherever there might be suitable qualified staff.

Internet based technology markets, idea generation and problem solving systems have been established. Large companies such as IBM have decided to become more technology intensive (i.e to find ways of selling expertise and technology or R&D`capability). IBM and Intel and other organisations have also established internal venture capital organisations to acquire small enterprises when the technology they have developed at their own risk reqches sufficient maturity. This strategy reduces the risk to them of early stage research (but does not eliminate the overall cost of such research to an economic system). They acquire tested technology, experienced staff and a business simultaneously. They can licence the technology externally as well as use it internally. This supports the options-thinking approach (Newton et al 2004) which changes the managerial mindset from perceiving R&D as a cost to the business towards regarding it as an investment. There are other ways in which a trend towards entrepreneurially financed R&D is becoming established.

Efficiency and productivity within **R&D activity is hence closer to creativity management than to cost effectiveness**. Creating a conducive environment is considered important. Science parks are often attractive environments, in prestigious locations close to universities, because in advanced economy countries where science and technology parks are more likely to be found it can be difficult to attract high calibre R&D staff.

The above trends are both the result and the cause of ‘cost drivers’.[44] In many situations the ‘cost’ is not recognised but instead research is considered as an investment opportunity. In other cases it may be appropriate to consider the importance of purchasing or procurement systems and more policy interest is being focused on the potential of large company or government procurement policies to influence or stimulate R&D amongst suppliers. The automotive industry for several years has been applying this philosophy amongst its component supply industry, as it did with quality management; it is not by specifying what R&D must be undertaken but by expecting R&D opportunities to be identified independently. Thus the status of methods in the Table below is dynamic and what might be internal one year becomes external in a later year.

[44] The members of the expert group mentioned increasing costs in wages, industry-specific factors, outsourcing, and the regulatory environment as significant cost drivers in the past and at present.

Table 20: Internal and external perceptions of R&D and cost pressures ('drivers').

R&D management methods	
Internal business pressures on R&D	External influences on R&D costs
TQM BPR Core competences Concurrent engineering Laboratory notebooks knowledge management (-) Collaboration (-) Strategic exploitation of technology (-) R&D as a business (-)	Regulations (+) More complex technology (+) Low-hanging fruit is eaten (+) Short-termism (-) Salaries, attractiveness of R&D careers (+) Environmental issues Customer expectations Larger-scale equipment, consortia and science infrastructures (+) ICT support systems (-)

Source: own depiction

The effects of the methods shown in the table can be briefly explained: The colour (sign) of an item represents a likely effect on costs – blue (negative) seems likely to reduce costs, red (plus) to increase costs and black to have a neutral effect. These assumptions can be examined in the study and some will be geographically dependent – for example the attractiveness of R&D careers and salaries.

BPR (business process reengineering) as a technique is neutral. Its effects depend on the reasons it is applied and in the 1990s, which is the case for R&D in Fig 10, it was applied by consultants to increase shareholder value. Its effect was often to eliminate R&D from the corporate balance sheet (by spinning off or by closure). A few years later there was business interest in knowledge management which can be interpreted as a corrective measure after the expertise lost from BPR (and the lack of organisational 'slack') meant that innovation was inhibited.

It is difficult to classify all the items with a positive or negative effect on costs. In some cases there could be encouragement and promotion of R&D benefits with effects either way. More analysis of all these methods and trends is therefore needed.

Open innovation changes how R&D risks and investment exposure can be shared and minimised. It uses and simultaneously changes how portfolio management, project selection and termination, roadmapping and other management methods are used. It changes the structure of R&D organisations and systems. It is not a single step change but an evolution – innovation in the innovation process and the roles of R&D. The costs of R&D must be evaluated against this moving backcloth. Moreover such trends cannot easily be attributed to a specific date within an organisation. They started for many companies inperceptibly - long before any explicit decision to adopt an open innovation approach might be taken. Thus analysis of cost trends 'before and after' are problematic and can probably only be based on subjective impressions.

Concurrent engineering facilitated faster more frequent innovation by compressing R&D, design and production planning. This introduced efficiencies, improved organisational communications and could have resulted in higher quality goods or outputs. But it could also lead to more intensive performance peaks in project lifecycles.

The strategic exploitation of technology gives greater importance to the technological capability, IP and expertise of a company and thus makes investments easier. It might also bring about business independence and profit motivation, with consequent increases in overall costs.

To counter the inflationary pressure of **pharmaceutical research, for instance,** several suggestions have been made (e.g. PWC, 2007):

- More technology should be used: ICT and pharmacogenetics;
- Outsourcing clinical trials and other parts of the R&D process;
- Fully integrated research networks should replace older less flexible organisation principles;
- New testing paradigms, e.g. testing against the state of the art instead of placebo;
- Value based pricing, based on the marginal clinical benefit of the new drug.

Perhaps the most significant focus of attention for this study must be the increasing complexity and challenge of technology development. It is intrinsic to R&D that projects are not repeated so there isn't the same learning curve effect as for volume production systems. As 'low-hanging fruit' is eaten, it seems inevitable that the cost of R&D must increase (as seems the case with new drugs). But to pick higher fruit is not the same R&D requirement. So costs cannot be directly compared.

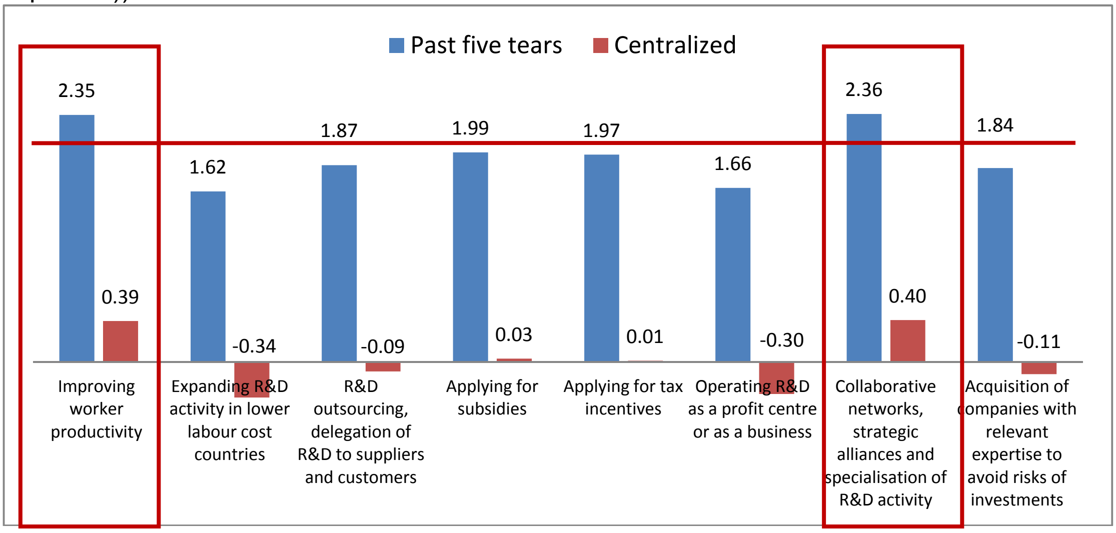
5.2 Organisational responses: Findings from the empirical study

5.2.1 Companies

The scores on **management strategies and cost indicators** give a clear picture of the landscape how management deals with strategic and cost related questions of R&D. The response rates for these questions are the highest of the survey, hence their accuracy is also the highest of all categories of answers. Main managerial instruments turn out to be 'collaborative networks' and 'improving worker productivity' as exhibited in Figure 39. Of particular interest is that expanding R&D activity to low cost countries was considered as least important to contain research costs.

One would expect that operating R&D as a profit centre to generate income and thus subsidising the overall cost of research would be an important strategy; on the contrary, in this survey, this does not appear to have great relevance.

Figure 39: R&D management and strategies (Importance from 1 (not important) – 3 (very important)).



Source: EU Survey on Cost of Research (2011)

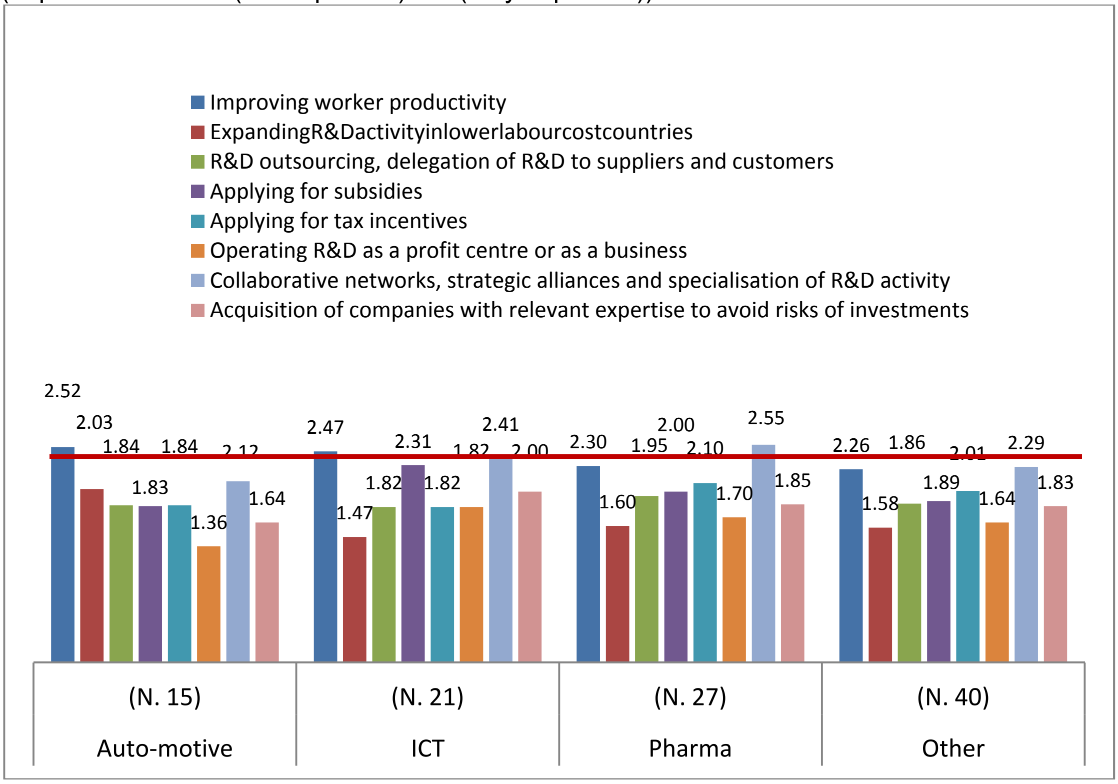
There are **some differences between the sectors, size and location:**

In Figure 40 we have the effect of R&D management and strategies on costs by sector. In all sectors improving worker productivity and collaborative networks, strategic alliances and specialization of R&D are the most important factors reducing R&D costs. But, while for automotive and ICT improving worker productivity is the first most important, collaborative networks are the first factor indicated by companies belonging to pharmaceuticals and other sectors.

Table 21 reports the same figures but this time by company size. Again, improving worker productivity and collaborative networks, strategic alliances and specialization of R&D are the most important factors. But for small firms the first is more relevant of the second, differently from medium and large where collaboration and specialization are more relevant.

No differences emerge on this part between EU and non-EU companies: Table 22 shows that for both collaborative networks and specialization is the first factor followed by improving worker productivity.

Figure 40: Effect of R&D management and strategies on costs by sector, (Importance from 1 (not important) – 3 (very important)).



Source: EU Survey on Cost of Research (2011)

Table 21: Effect of R&D management and strategies on costs by size, (Importance from 1 (not important) – 3 (very important)).

	Small (N = 42)	**Medium** (N = 30)	**Large** (N = 31)
Improving worker productivity	2.48	2.25	2.18
Expanding R&D activity in lower labour cost countries	1.49	1.88	1.64
R&D outsourcing, delegation of R&D to suppliers and customers	1.79	1.80	2.09
Applying for subsidies	2.05	1.96	1.91
Applying for tax incentives	2.01	1.86	2.00
Operating R&D as a profit centre or as a business	1.61	1.62	1.77
Collaborative networks, strategic alliances and specialisation of R&D activity	2.23	2.31	2.64
Acquisition of companies with relevant expertise to avoid risks of investments	1.78	1.80	2.00

Source: EU Survey on Cost of Research (2011)

Table 22: Effect of R&D management and strategies on costs: companies from EU versus Non-EU countries,
(Importance from 1 (not important) – 3 (very important)).

	EU (N = 89)	**Non-EU** (N = 14)
Improving worker productivity	2.30	2.64
Expanding R&D activity in lower labour cost countries	1.65	1.45
R&D outsourcing, delegation of R&D to suppliers and customers	1.84	2.09
Applying for subsidies	2.05	1.64
Applying for tax incentives	2.01	1.73
Operating R&D as a profit centre or as a business	1.64	1.73
Collaborative networks, strategic alliances and specialisation of R&D activity	2.31	2.64
Acquisition of companies with relevant expertise to avoid risks of investments	1.83	1.91

Source: EU Survey on Cost of Research (2011)

It is also of interest to compare our findings with a recent study of the R&D Scoreboard firms by Cincera et al. (2011) which explicitly asked for the importance of public policy for supporting R&D activities inside the EU in their 2008 survey. They found that tax incentive and direct public aid was considered as highly important by many firms while policies which foster co-operation were considered of moderate importance.

The case studies show that there is a trend towards the use of **innovation intermediaries and the provision of R&D as a service**. This affects both companies and PROs – in different ways. In the case of PROs as technology providers it may manifest via the marketing of consortia R&D services. In the case of companies as technology clients it can manifest as consortia purchasing. This trend is an extension and refinement of the pervasive shift over more than two decades towards collaborative networks and open innovation; companies are becoming more specialised in their R&D capability and focus.

Personnel costs are the main cost category and it might be assumed that companies will strive to control salaries. However, a direct focus on reducing **personnel costs** within the existing organisational structure is not the adopted approach. Significant changes have occurred in the last twenty years to the way that R&D and innovation is organised; the effect is to control costs sublimely by adjusting what is done in a particular R&D context. Here we focus on personnel costs per se.

An alternative perspective: capital costs exceed labour costs.
ENI is an Italian energy company. The company's costs of research are dominated by capital costs for testing new processes and technologies rather than labour costs. An oil-well for testing a drilling technology is five times the cost of all the company's R&D personnel. Cost development is driven by two main determinants. First, oil has become increasingly difficult to find, creating progressively more difficult conditions on a global scale such as working in deep water, in Arctic areas, and dealing with poor oil quality. These difficulties result in higher costs as more research into new materials and processes are required. Second, some technological frontiers have been reached and breakthrough research is needed including in technologies in complementary assets. For example, ENI has reached the currently lowest levels of concentration of sulphur in diesel fuel, and current measurement instruments are not yet capable of detecting further improvements in the levels of sulphur.

R&D managers do not appear from cases to be explicitly **concerned about controlling salaries.** In fact they are likely sometimes to find exceptional ways to pay higher salaries than the norm to attract or retain employees with particular expertise. It is not easy or desirable to minimise salaries since the recruitment, retention and motivation of highly qualified staff is a crucially important element of good R&D management. This is especially true when in several countries, including North America, universities have difficulty to attract as many science technology engineering and maths students as they would like. So the supply of graduates is below the optimum. The international flows of postgraduate students contribute to the international R&D talent pool. For example, a manger from a software company report that China is on their radar as an international source of talent: *"Central Europe is still is an attractive business location. In future the question will be where do I get the best people? China is getting attractive in this case. It is dramatically catching up concerning the quality of universities."*

It is desirable for knowledge management and organisational capability to **keep a relatively stable portfolio of work which stretches the expertise of employees.** R&D is often organised in multi-disciplinary and multi-functional project teams and is not confined to a core staff working in laboratory environments. It is important for knowledge management and organisational capability to maintain a momentum of interesting work and to demonstrate scientific leadership and excellence. This extends to the conditions of work and job definitions; encouraging creativity, links with universities, and publications are desirable HR objectives. Furthermore, it is the volume of work which drives the cost, because R&D is labour (or knowledge) intensive. If more work can be found to employ higher numbers of staff without increasing equipment or facilities capital costs then the proportional significance of personnel costs would be reduced.

The labour market for (good) researchers is a global market, so competitive salaries are needed to attract excellent people. Good infrastructure (equipment, facilities, proximity to good relevant universities and related companies and institutes etc.) also is needed. According to Boehringer Ingelheim IMP interviewees *"excellent researchers need top equipment and one have to offer access to this facilities as otherwise one is not able to attract those people".* Maintaining an image of excellence is important; where patent and publications are used as a performance indicator it should ideally be to evaluate this intangible at an organisational level rather than to deploy a Tayloristic work study approach at an individual employee level.

Thus companies can expect to pay higher salaries in the future in order to employ more highly qualified staff. This is also the case in India and China and other low-cost countries. In fact it may be even more true in those countries as R&D activity expands. There is **evidence of salary inflation** in those countries. The CEO from a Chinese firm (Ruijie Networks) maintained that *"China's competitive edge in high-tech manufacturing due to low labour cost is diminishing."* There is growing evidence of salary inflation as managers and R&D personnel with and education and work experience in Europe or North America accept jobs in Asia. Their reward structures change the expectations of indigenous workers. In India in particular the costs of personnel management are high because employees change jobs frequently for career and salary progression. The total number of R&D employees (foreign and indigenous) in Asian R&D sites can still be quite small as a proportion of MNC R&D budget and so this moderates effects of salary increases on overall R&D costs.

Nearly all of the case studies involved discussion about **outsourcing and collaboration** with external partners. An initial point involves the location of R&D offices. Philips maintains external offices in Germany, UK, China, Indian and the US to meet particular market needs rather than to reduce costs. Homag operates an R&D facility in Poland as part of its cost management strategy but in general the company uses facilities outside Germany to address excess capacity or serve the local market (as in its Shanghai facility) rather than to reduce costs. Likewise, Bosch has research locations in six countries but not without regard for maintaining a strong presence in its Stuttgart research centre. DSM has significant R&D investments in China and the US, with its R&D centre in Shanghai created to advance local R&D. Boehringer Ingelheim's IMP operates seven global skill centres in Germany, Austria, and the USA to enable information exchange, shared technology development, specialised support, and emerging technology assessment. GDF Suez finds that the European skill base is a more reliable workforce than elsewhere even though the company has R&D locations in Brazil and Shanghai. So too does the Fagor Electrodomesticos case mention the reliability of the European workforce, even though it is considering an R&D site in India. The company undertakes further cost balancing between its less expensive headquarters location in Spain and its R&D facility in France. It should also be noted that the political ramifications of outsourcing R&D work are underscored in some of the cases.

Although manufacturing and IT as well as accounting and human resources have been outsourced, the outsourcing and offshoring of R&D was initially considered inadvisable. But has now become expected in many industries to a significant but limited extent. Different companies have learned from experience and are still learning how to diffuse knowledge gained from R&D throughout their global organisation as well as how to effectively manage geographically dispersed project teams. There are various reasons for establishing international R&D centres; cost is not the primary reason. The trend does raise fundamental strategic questions about the spillovers and strategic benefits for a company as well as the regions in which the centres are established. It is not clear that the longer term implications are fully appreciated. We are still learning the consequences for the economy of outsourcing and globalising manufacturing so enthusiastically, with some variations in corporate governance structures (as in Germany and Japan) providing different learning perspectives. The offshoring of R&D to India and China in particular has been more rapid and the lessons about its effects are more difficult and complex. Investing R&D in North America, where it is usually access to better facilities (including more expensive equipment) that is the motivation is a different analysis. Equally, attracting R&D investment into Europe is a different analysis. What we see in all perspectives is that cost is not the primary concern. Interestingly the Motorola case may be a weak signal for a reverse trend; it has integrated ten international research centres in order to focus on innovation objectives rather than disparate research objectives.

Non-European companies: diverse approaches to locating R&D

Case studies of one Chinese and four US firms illustrate that these companies are concerned with managing costs. However, most view research costs as a strategic investment rather than a cost line to be micro-managed. In this context, locational decisions concerning research facilities are important and somewhat, though not wholly, related to cost considerations. Texas Instruments has facilities in 30 countries and was one of the first semiconductor firms to establish R&D facilities in lower cost geographies, opening its Bangalore India facility in 1985. Outsourcing of process and manufacturing research has driven some of these research locations. However, Texas Instrument's locational decisions are not driven solely by cost, as access to markets and talent are of equal strategic importance. Tellabs, which develops and provides telecommunications equipment to large carriers, has multiple R&D locations which help the company with cost management. Tellabs also uses R&D partnerships in lower cost geographies. Nevertheless, the last four years have seen Tellabs consolidate R&D into fewer locations to promote greater alignment with strategic business units as well as to reduce expenses. Motorola, which operates in the mobile device and network industries, has reduced its global locations to enhance coordination and achieve greater product synergies and returns on the research investment. However, development, as opposed to research, continues to be outsourced to foreign locations. Medtronic, which makes electronic medical devices, performs larger clinical trials in the US but early stage clinical work is conducted in Eastern Europe. To manage costs, facilitate market entry, and gain access to scientists, Medtronic maintains R&D facilities in 10 countries including five European countries. In contrast to the US cases, Ruijie Networks does not have remote R&D offices outside of China because of legal, cultural, and language barriers, although it does operate marketing offices outside the country. Ruijie Networks is facing precipitous increases in research labour costs, which it seeks to address through development of high-end innovative products.

External partnerships are sometimes applied to facilitate cost management but this is achieved ultimately via a strategic and longer term structural effect in the 'knowledge production' system. It is an industry trend to derive advantage from collaboration rather than an individual company objective to obtain competitive advantage. Philips uses a strategy for "inside-out" innovation – through participation in external projects, offering laboratories as user facilities, and selling IP – and "outside in" innovation through external collaboration. A key R&D management consideration at Rhodia relates to decision as to which competencies to develop internally and for which ones to rely on external partnerships, including the value chain. *"We will not develop any competence at any cost"* according to an interviewed R&D manager of Rhodia. The scale of capital investments in the energy sector requires external partnerships, according to GDF Suez. The challenge is identifying the most suitable approach for each technological engagement, be it in-house research, sub-contracted R&D, partnership-based R&D, acquisition of R&D based operations, further technology watch or abandoning a particular technology choice. Fagor Electrodomesticos engages in collaborative product introduction with other manufacturers but notes that using external sources is actually more expensive (because of management costs) even as it offers greater flexibility. Texas Instruments performs most of its research in-house, but makes extensive use of strategic alliances with foundries for process R&D cost management. In addition, the US cases studies exhibit prominent use of acquisitions as a cost effective way to enter new markets, increase capabilities, and add new products.

Technology alliances along the whole value chain often including competitors play a key role in managing portfolios. Similarly, using the most appropriate organisational vehicles for different types of research is an important strategic lever to ensure the greatest returns from research investment. Spin-out companies are one way of capitalizing on research activities, acquisitions are another.

Nearly all the cases studies refer to **university and government laboratory collaborations**. DSM has scientific relationships with 2000 university departments as well as research centres. Rhodia's partnership with CNRS addresses disruptive technologies and several other cases stress the ability of university partnerships to address long-term timeframes. The local proximity of Ikerlan and University of San Sebastian is favourably viewed in the Fagor Electrodomesticos case. Some of the US cases report that less work is done with universities because of lower budgets for speculative research and rising overhead and contracting costs with universities.

These collaborations result in new value-chain relationships and R&D specialisation where knowledge and technology is processed at a more sophisticated level. R&D itself is increasingly becoming an industry and not just a business function. Universities are playing an increasingly important role in industrial R&D, especially in basic research but also in fundamental aspects of applied research. Businesses are not just sponsoring university teams but are working more closely and interactively with them in various ways. PROs can find new services to offer in this milieu (both as research providers and as innovation intermediaries). In such a system as in any business, securing a premium price for products and services (knowledge) or being engaged in prestige projects and consortia becomes a commercial objective. Rather than this be regarded as a cost increase it can be regarded as a value-adding activity. In other words the notion of cost depends on the business model in operation. Outside-in and inside-out aspects of open innovation imply that R&D is not simply specified but can both be stimulated and be a stimulus. Managers in these open R&D systems find 'customers' (or partners) for R&D outputs as well as arrange R&D projects for 'customers' This model contrasts somewhat with the familiar pipeline model that is still a feature in the pharmaceutical industry but, as is explained elsewhere, the pharmaceutical industry blockbuster model of justifying R&D is under pressure.

In the future five years, interviewees suggested that there will be greater use of open innovation methods, in part of manage costs. Fagor Electrodomesticos exemplifies this approach with plans for lower wage costs for R&D in Asia and greater use of worldwide alliances. Boehringer Ingelheim's IMP predicts the **share of R&D costs for facilities and equipment will increase** but at a slower pace, whereas quality assurance costs will increase.

One response to the interdependence of different technologies is to develop **standardised**, **open, platform-based products in co-operation with partners**. However, this is not to say that the result is a standardised product. On the contrary, such platform standardisation allows research costs to be controlled and technological complexity leveraged for competitive advantage particularly in sectors and markets in which competition on the basis of cost or is no longer the primary differentiator.[45]

Due to the **rising patenting costs** some companies are more selective in filing patents. Motorola previously viewed patents as an investment and developed a large portfolio, but now is more selective in patenting to maintain IP parity with competitors. Homag also monitors competitor patent positions as part of its strategy to be selective in patenting. Medtronic reports that extensive litigation has added to the rise of patenting costs. In contrast, Bosch seeks to maintain its innovative and technological position through the filing of patents, with cost issues not substantially mentioned as an important consideration. Boehringer Ingelheim's IMP and Bracco Imaging likewise use patenting as an output and productivity indicator rather than a cost consideration (see also below).

Funding R&D with venture capital

In some industries there has been a trend to support R&D for breakthrough and incremental innovation using venture capital instead of internal corporate funds. This modifies the risk reward balance and can provide more flexibility and entrepreneurial management. Some large corporations (e.g. Astra and Philips, which were study as a case here but also other companies worldwide) have established their own venture capital funds as part of the R&D strategy. They progress with active business development management (which might be contrasted to stage-gate R&D project management) as independent (and perhaps R&D-intensive) businesses. The combined assessment of cost, risk, relevance and success probability for venture capital funded projects is thus more flexible and entrepreneurial than for projects justified within a single enterprise.

Although the establishment of such funds predates popular use of the term 'open innovation' by over a decade it can nevertheless be regarded as one form of the open innovation phenomenon. It has primarily been considered as a strategy for reducing R&D risk rather than cost. R&D supported by venture capital is evaluated using strategic criteria different from those used internally for corporate portfolio management. The vitality over several years of venture capital involvement in early stage R&D might be used as a proxy measure for the relative 'cost' of R&D since it reflects

[45] These findings based on the case studies support hypotheses 1 and 3.

commercial judgements of the viability of R&D projects and their exploitation prospects, independent of a particular corporate strategy or corporate constraints (but dependent on the vitality of equity markets).

In the case studies we explored in more detail the role of **public policy**: Case study interviewees referred to a range of tax, technology transfer, and regulatory programmes in the context of their companies' R&D efforts. R&D tax credits were positively viewed as leading to increased research activity (see for example the Rhodia, Philips, and Fagor Electrodomesticos cases). Following the introduction of the R&D tax credit in France, Rhodia reported that this measure had an influence on their R&D location decisions and enabled the company to retain R&D capabilities that would have otherwise been moved to lower cost locations, such as China. Rhodia's interviewees also had positive comments about national programs to accelerate the timeframe for bringing innovations to market. The Philips case illustrates how public policy was used to retain jobs during the 2009-2010 economic downturn by enabling R&D employees to temporarily locate in the local public research organisation or university. Boehringer Ingelheim's IMP's access to city funding programmes enabled the company centre to lower its infrastructure and database costs. Positive effects of green regulations in promoting market development were evidenced in some of the case study interviews. For example, the Fagor Electrodomesticos case reports that green policies have encouraged replacement of household appliances.

Visa regulations were not mentioned in the European cases, although several of the US cases suggested that these regulations restricted their hiring ability. Biomedical regulations were highlighted for their effect on raising research costs in the pharmaceuticals and biotechnology industries.

Attitudes toward FP7 programmes were mixed: Company case studies show a range of approaches in this regard. First, some companies cluster their research functions into a local/home country geography or by industry, but others move toward more multi-country relationships with partners or supply chains to reduce the cost of research. Some firms have favourable preferences about large scale grant awards while others find them to pose additional administrative and coordinating costs and go against the companies' competitive needs for private R&D.

The GDF Suez case referenced positive effects of FP7 on encouraging new partnerships across energy sources in which the company otherwise would not have participated. These partnerships were seen as laying the groundwork for smart grid activities. Rhodia's interviewees also reported that the European Technology Platforms encouraged valuable networking. However, concerns were expressed about FP7 programmes by Rhodia being too bureaucratic and returns too uncertain as a result of the pre-competitive and long-range nature of the projects.

5.2.2 Public Research Organisations

R&D management strategies for PROs reveal some patterns similar to those found for companies (see Table 23). In parallel with companies the most important R&D strategies for reducing costs are improving worker productivity and collaborative networks. Specific of PROs are two other strategies: eliminating less important R&D activities and establishing units to commercialise the results of R&D. This is exhibited in Table 23.

Table 23: R&D management and cost indicators in PROs (Importance from 1 (not important) – 3 (very important)).

R&D Management strategies in PROs	past five years N = 32	Centralised
Improving worker productivity	2.59	0.73
Expanding R&D activity to low cost countries	1.28	-0.58
R&D outsourcing etc.	1.22	-0.64
Eliminating less important R&D	2.16	0.30
Establishment units to commercialise R&D results	1.97	0.11
Operating R&D as a profit centre etc.	1.88	0.01
Collaborative networks etc.	2.50	0.64
Acquisition of companies etc.	1.28	-0.58
Average	1.86	

Source: EU Survey on Cost of Research (2011)

The most important strategies for reducing R&D costs from the survey are approved by the case studies concerning "improving worker productivity", "eliminating less important R&D activities" and "establishing units to commercialise the results of R&D". However, "collaborative networks" were not mentioned as an important R&D cost management strategy within the interviews. It seems that this comes from the fact that PROs are used to work and have always worked within collaborative networks, as a nature of scientific work. Probably, collaborative networks were therefore not regarded as cost saving management strategies for R&D by PROs within the interviews.

In general, the non-university research sector is very heterogeneous. While some PROs perform quite well and have grown in the past, others are struggling, mainly because of declining public funding and the necessity to raise private funds and contracts. However, due to the current cost base some of these are not very competitive in the research market and have obstacle to increase contract research revenues and commercialise the research outputs.

The case studies offer more in-depth knowledge about how PROs cope with rising research costs. When regarding the management of R&D costs the mostly mentioned strategies are **strategic alignment of R&D activities, rationalization, and reorganisation**.

Many organisations have reorganised in the past and even merged (e.g. Tecnalia). Although some organisations also argue that thereby particularly administrative costs can be saved, the main reason for major organisational measures is to achieve critical mass and greater scope, and thus also to access different types of funding and revenue generating opportunities. Increasing scale as well as the integration of disciplinary research approaches is evident in cancer research where large research centres have recently been announced, often close to or incorporating universities research centres and / or hospitals. In this and other medical research areas the role of charities as major sources of funding is very significant; they help to coordinate research strategy and can be involved in commercialising related technologies.

Representatives of Scandinavian PROs, such as VTT and SINTEF, pointed out that a **flexible organisation of R&D activities** is an important efficiency aspect, which means the ability to move researchers between R&D areas. Reinforcing the points made above about scientific leadership and the important role of the image and reputation of a research centre to motivate and inspire creative research it should be remembered that flexibility in the employment and deployment of creative knowledge workers is not best managed in the same way as office, production and managerial staff. **Open innovation** (and its implications for R&D) is a very significant way to provide flexibility. It encapsulates what was being sought in previous years under the guise of 'contracting out' R&D, running R&D 'as a profit centre' and then running 'R&D as a business'. There are likely to be more creative ways devised in the future with implications and opportunities for PROs as well as businesses – in fact these initiatives will blur the distinction between the two categories. Already we see crowdsourcing and competitions and open problem-solving portals being used as a flexible R&D resource. At the other end of the spectrum TNO[46] is a partner in a global alliance of R&D institutions (including CSIRO and CSIR in South Africa, Australia and India). Although such initiatives might sometimes only comprise the signing of a memorandum of understanding, they can lead to increased mobility (for training and experience), joint project bidding, and flexible deployment of staff on a global scale. At the same time such alliances are likely to retain (national) institutional autonomy which for PROs is more intrinsically important than for corporations.

Most of the PROs are using outsourcing strategies in order to contain costs. SINTEF and VTT mention ICT services and INRA mentions support functions as key aspects of their outsourcing activities. However, some of them, e.g. COSTB or INRA, limit networking activities and their outsourcing activities in order to **secure their intellectual properties**. This subject – how to extract value and protect at the same time – is at the frontiers of management practice and research.

The **maintenance of offices abroad** is attractive from the aspect of research co-operation and not for the reason of low salaries. For PROs such decisions involve a wider set of criteria than market knowledge or cost or global presence for a business; it requires deeper thinking about the need for PROs to maintain expertise in certain areas (and sometimes at the leading edge of research) in order that the PRO can be an effective gateway. Thus the development and retention of experienced people residing in particular locations may be a critical factor rather than specific project results. Learning by performing R&D and being a sophisticated customer or partner is closely related.

The fact that cost is not a primary factor is reinforced by the DLR case: *"We are thinking about Singapore at the moment."* There is currently build up a large centre for aviation. DLR is interested in being there and working together with the manufacturers (e.g. of jet engines), but not for the reason of low salaries".

TPF considered that interpersonal communications and networks were not sufficiently developed to help stimulate better use of the cost effective R&D resources in Poland and other Eastern European countries. There was a great potential available.

SINTEF closed its office in Poland in 2010 because they were unable to exploit the possible lower R&D costs. In the future other strategies will be pursued. The presence in another country is seen as an expensive and not necessarily correct tactical approach.

Some PRO (e.g. DLR, ELLETTRA, TECNALIA) are equipped with **large infrastructure facilities. This is associated with a heavy 'fixed cost' basis**. These PROs try in particular to increase the efficiency by various strategies such as offering specific services, technology transfer, etc. The maintenance, service and training for researchers and technicians have grown considerably at the same time. In Germany, the DLR has the advantage to benefit from the "pact for science and innovation" ("Pakt für Forschung und Innovation") which was defined

[46] TNO was not examined as an explicit case study but is referred here as an interesting example.

by the German government. Together with the science centres the government established certain aims. If the science centres are now trying hard to meet these goals their budget will be increased by 5% for the next five years. And due to the financial crisis of last year the government introduced several business activity support programs. From these there was given extra money into the building of large devices. Thus, the German DLR is in a rather lucky financial position compared to other organisations.

Shared scientific research facilities in response to increasing costs are another way of managing the increase in the cost of facilities and equipment. This often involves public and private players. For the public sector partners this has led to considerations regarding the cost model to be adopted in a climate in which PROs are increasingly expected to pay their own way.

Only a few PROs, such as INRIM, indicate that they do not have **specific cost management strategies**. However, INRIM puts specific emphasis on the selection of new projects using informal criteria such as “past success in the field” and “reliability of the new project”. Rather than focus exclusively on cost management strategies or cost indicators it is more desirable to consider performance management and performance measurement methods. In such approaches the criteria used and the indicators devised should be ‘designed’ for each organisation and its requirements (van Drongelen et al., 1996). ‘Impact’ is becoming a more recognised indicator even though it might at first be difficult to design a ‘template’ impact statement. Qualitative appreciations of impact may be more than sufficient. Performance measurement in R&D builds on a long history of developing and applying techniques for project selection, project management (e.g. stage-gates), and portfolio management. Justifying the expenditure rather than cost controlling the expenditure has been a stronger emphasis. Securing venture capital finance for research has emerged over the last two decades in bio and other technologies. This requires a different level of investment justification and again it is the research results and their conversion into value that it is more important than cost control. Justifying public investments in R&D need not be considered different in principle from raising venture capital but the methods and terminology used for extracting value – exploiting the results for public benefit – may need adaptation. The NPL case raised discussion about focusing on the value (rather than cost) of R&D; this is in line with the valuation of intangible assets and options thinking.

Commercialisation of research results

As commercialization of research results is a very important topic some of the PROs, such as AIT, SINTEF, VTT and DLR, even have established organisational units with this aim. DLR, e.g., tries to commercialize research results in many ways, as one DLR-manager put it: *“We try to bring the developed technologies of a certain research field also to other areas and to exploit them commercially. This is called “transquer” within DLR, which means to find application from the aerospace field for other industries.”* Representatives of Scandinavian PROs stressed commercialisation and start-ups as new cost and revenue source.

As PROs have started to **operate R&D as a profit centre or as a business** they control and contain research costs by using measures such as co-operations with respect to purchasing, outsourcing of administrative services, improving of project management and so on. However, there seems to be more focus and managerial attention on **inside-out based open innovation strategies**, i.e. licensing, technology transfer, spin-off activities, etc. which in turn can raise productivity by maximising the financial returns of the investments. The commercialisation of research by involving different partners is hence a significant trend in many PROs, it is hence not only about creating knowledge, but to translate it into financial value.

BBC R&D and open innovation – exploiting the role of R&D in regional and international economies – putting R&D into the heart of business operations[47]

A focus on R&D in the BBC (British Broadcasting Corporation) was originally selected to illuminate potential cost comparisons associated with laboratory relocation. A strategic decision had been made to move R&D capability from London to a new base (Mediacity) in Manchester. The motivation for the decision was not cost reduction as expected, but a desire to extend and embed its open R&D and innovation philosophy into the regions.

The BBC has a directive to apply R&D towards improving the UK creative industries as well as the BBC's competitive position. Clause 87 in the charter explains that it has a responsibility to maintain a centre of excellence to broadcast and creative technologies and should conduct those activities in association with academia and industry. The BBC R&D department might develop an idea - for example the video graphics system Piero - and then license it to a commercial partner who will productise it and even sell it back to the BBC. *"It can be a circuitous route but by doing it that way we generate a wider economic benefit."* (Wired.com 2010 interview with Matthew Postgate, Controller of R&D)

In addition to encouraging and working in a large number of collaborations of various kinds BBC R&D is concerned with technology transfer. The overall aim of this is to ensure that the BBC gets maximum value out of R&D work, whether that be in the form of audience impact, revenue, or cost savings back to the BBC.

R&D helps the BBC as a whole to operate in an open collaborative way, with content providers and other types of creative industry companies in the UK and internationally. It does this not just to improve the effectiveness of R&D but to improve the overall operation of the BBC. A recent BBC review of technology recommended that the R&D Department should "come into the heart of the BBC " and be integrated with technology strategists in a new Technology Group

The Royal Charter and licence fee method of generating income influence the open system of publishing information including scientific papers and committee meetings. It also means that R&D budgets are closely monitored and open to public scrutiny. Strategic research, takes around 10 per cent of the department's efforts and looks at technology that could become significant in a timeframe of five or more years. Applied research looks at technology likely to be relevant in the next one to five years. It takes up around 45 per cent of the department's time and resources and can cover work such as developing code which could feed into upcoming projects, filing patents or examining new production techniques.

One of the potential beneficiaries of the applied research is he proposed IPTV platform, Project Canvas, a collaboration between the BBC, BT, ITV and others. Project Canvas will integrate applications from previous R&D effort (subject to IP negotiations about what is or is not included). This illustrates how R&D can be used to develop R&D capabilities as well as technologies and innovations. Projects include HD for the Freeview service creating the DVB-T2 standard, investigating white space spectrum, and green technology.

A CSTB manager reported that cost increases are associated with developments regarding the public mission of the CSTB*: "As a result of this regulatory pressure, any new product, such as for instance new concrete, needs to be tested in all these respects."* He expressed the view, however, that the European Commission would play a key role in decreasing this regulatory burden by helping to align regulations in different European countries analogous to the role that the Schengen agreement played with regard to border controls. CSTB also sees a clear role for public policy in supporting the emergence of a strategic research agenda for the construction area. For the CSTB, a key decision relates to the question of whether public good considerations are strong enough to justify not allocating real costs to individual users

[47] See also: "How BBC R&D is laying the foundations for the broadcasting future", http://www.silicon.com/authors/tim-ferguson-39026286/Interview: Controller of BBC Research and Development, Matthew Postgate by Tim Ferguson, 13 January 2010.

and activities since a direct accounting approach would make all research using an installation like a wind tunnel extremely expensive.

With respect to **EU FP projects**, PROs are not being able to charge the real cost which is considered as highly problematic by most respondents. The **costly auditing and reporting requirements** are raising research cost as well according to the respondents. Moreover, those organisations providing **large infrastructure** argued for a further and **better coordination** with a view to capital investments. This requires merging national efforts in order to increase the performance of fewer installations by facilitating more diverse usage. ELETTRA, one of the PROs running a large infrastructure, for instance, argued, that the lack of state fund for the management of the new infrastructure could reduce its use while a new frame for the management of European consortia of large infrastructures, if a political convergence among the countries is found, could represent a positive solution to these financial impasses.

6 Cost measurement and research productivity

6.1 Evidence from the literature

In this chapter we will address the question how companies and PROs deal with research costs and productivity, how they measure, account for it and assess research productivity. In this context we also deal with the question to what extent research costs have an influence on managerial decisions such as fixing the R&D budget. While in the last chapter we addressed more generally the strategies to cope with research costs, in this chapter we focus on measurement and controlling perspective.

The difficulty to assess and measure research productivity was already mentioned above several times. As the nature of the process and quality of output of research is changing, comparisons over time and between sectors are difficult. Some findings using patents, for instance, have been presented above, which though reveal only weak reliable evidence.

In general, there is surprisingly **little literature on cost and accounting for R&D** compared to the bulk of literature which deals with the question how to control costs of manufacturing activities. However, in the last years, for instance, cost accounting techniques such as Target Costing and Activity Based Costing (ABC) were proposed for accounting of R&D activities which should deliver better information for decision making and the definition of product prices.

Within the (management) accounting literature recently a number of new approaches and instruments have been proposed to measure and report about the full range of intangible investments or resources, even though they do not comply with the strict definition by the accounting standards. This is hence to some extent a reaction of the lack of traditional accounting instruments to provide information for the management of intangible resources such as R&D and innovation and hence a response to the “inability” of a pure cost or accounting-based type of control of R&D activities using traditional financial measures. For accounting the identification, measurement, and allocation of different cost components to projects and outputs, i.e. cost-unit accounting, is particular difficult for R&D activities.

In this context, the movement towards the introduction of **performance measurement systems** (e.g. Kerssens-van Drongelen and Bilderbeek 1999, Godener and Söderquist 2004), intellectual capital management systems (Leitner and Warden 2004) and the preparation of value reports can be mentioned. The use of the Balanced Scorecard (Kaplan and Norton 1996) which adopts a wider framework than that of just accounting and financial performance measures proves this trend. The questions of quality, timeliness, and innovativeness are equally important as costs and quantity. Such instruments have also been applied by research organisations and R&D intensive firms. These models try to structure the R&D process with the aim to increase efficiency and the effectiveness of the system being aware about the specific of R&D activities.

In general, only a few studies have investigated the use of different forms of accounting (cost accounting, management accounting, or management control) for R&D activities. Studies such as the one from Abernethy and Brownell (1997), and Cardinal (2001) have investigated the impact of different types of management control. Abernethy and Brownell (1997) studying US and Australian R&D divisions found that the reliance on accounting controls (i.e. budgets, costs, financial targets)[48] has a positive effect on performance only when task uncertainty was very low. In contrast, personnel forms of control (e.g. selective recruiting, peer group self-regulation) were successful in context with high task uncertainty, e.g. when tasks are not repetitive, difficult to structure and underlying body of knowledge difficult to define. Cardinal (2001) examined how different forms of control (input, behaviour, output) effect the innovativeness of firms based on R&D projects of 57 US pharmaceutical companies. Using the three control types of Ouchi (1979) she distinguishes between input control (measured by the amount of scientific diversity and professionalisation), behaviour control (role of centralization and formalization of rules), and output control (i.e. goal specifity, performance appraisals and rewards of outputs). She found that input and output control had a positive impact on the number of product improvements, while all three forms (input, behaviour and output) of control were positively associated with the development of new products.

Davila (2003) studied the use of different forms of management control systems for the purpose of new product development based on a contingency hypothesis arguing that the use of control measures has to be aligned with the innovations strategy of a firm. He found that firms which followed a low cost strategy (i.e. importance of cost to the success of the product) also used more often cost information and information about profitability, which also had a positive impact on the project performance. However, there was no significant relationship with the use of budgetary information. Moreover, the higher the technological uncertainty of product development, the less often budgetary information was used for managerial decision making in the context of product development.

Although the mentioned studies examine the use of budgetary and cost information the literature has not addressed the question of the relationship between cost control, the budgetary process and investment decisions. The trend to introduce more sophisticated cost accounting systems can though be regarded as an indication that costs become more important for managing and controlling research activities. However, there is hardly any literature available investigating the effects of using sophisticated accounting systems for R&D control and decision-making. However, based on the arguments provided in the literature we can propose that the role of cost-related information does not play an exceptionally important role for budgeting and investment decisions.

Although there is a **trend towards the use of accounting and cost controls for R&D**, some authors still question to what extent accounting and management control systems are meaningful to be applied for R&D at all criticizing that a too strong control of costs may harm creativity and innovativeness. The real danger of management control systems (MCS) is that they may set wrong incentives and actors may strive to reach only the specified indicators and hence affect negatively the real business of innovation and problem solving. Amabile (1998) argues that MCS harm creativity; conversely, Nixon (1998) claims that they should have positive effects in facilitating co-ordination and learning with Wheelwright and Clark (1992) arguing for the benefits of informal and cultural forms of control which can be interpreted as an anti-accounting-based form of control. Davila (2000, 384), for instance, states that most studies investigating the application and impact of management accounting systems have found that such systems are “hindering or, at most, being irrelevant in R&D settings”.

[48] In general, the use of budgetary information, cost information and financial performance are considered as key elements of how managers control organisations. One could thus speak about a budgetary-based, cost-based and performance-based style of management control and accounting.

The reason for this infeasibility of traditional accounting control systems is that they have difficulties to measure clearly the outputs of the R&D process, which, though, is a precondition to learn about the effects of different forms of investments (inputs). Managers have problems to recognise how the output can be controlled by adjusting the input (Ouchi 1979, Hofstede 1981).

Thus, although formal accounting control is increasingly applied for R&D it is more prevalent for development activities than for research activities. Thus, due to the difficulties for managers to control R&D activities, cost-based accounting and control is obviously of less importance compared to other application fields such as manufacturing and the improvement of existing products. Clearly, the issue of cost control is also one of the chosen company strategy and type of R&D activities performed.

Thus, both, from the management and accounting literature one can conclude that classical cost control is (so far) not a key issue for R&D management. Although we can observe a trend towards the introduction of more sophisticated cost accounting and control systems, which indicates also that cost (awareness) have become more important for managing and controlling research activities, this is not a significant trend compared to the tremendous efforts (and papers published) companies are doing to control for instance manufacturing costs.

6.2 Cost measurement and research productivity: Findings from the empirical study

We now move on with presenting the empirical evidence based on our survey and case studies regarding the question how companies contain and control cost and what its relative importance is vis a vis other managerial actions.

6.2.1 Companies

Companies using R&D cost indicators are only few: 26%. On average the total percentage change shown by the industry indicator over the last five years is 16.74%, lower than the total percentage change shown by the company indicator (always over the last five years), equal to 27.70%.

When asked for the most important R&D cost indicator most of the companies mentioned the total project costs for the development of a new product or patent, or R&D costs as a percentage of turnover (or sales, respectively).

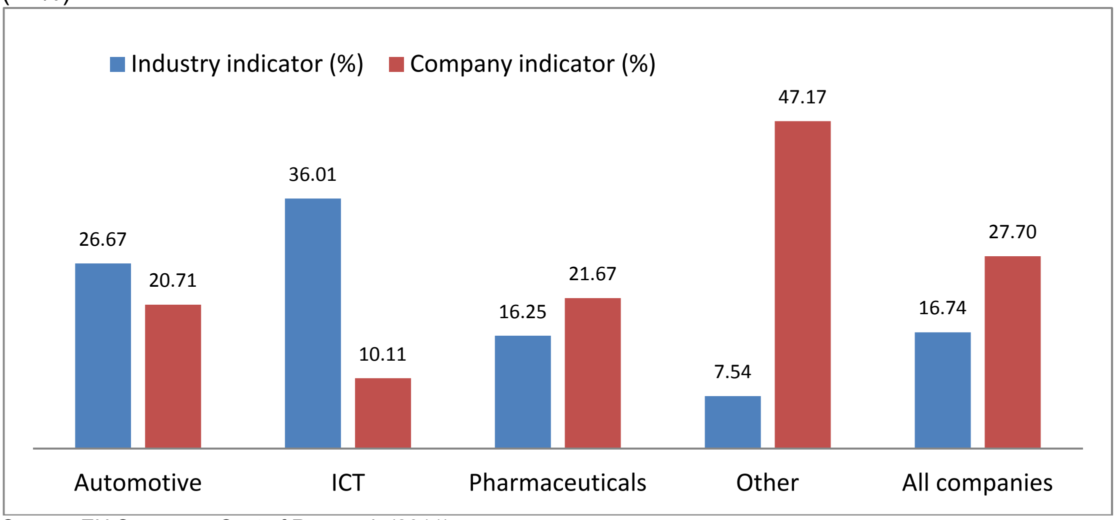
The following box lists typical indicators companies use:

R&D Cost indicators used by the studies firms:
Evolution of the total budget of R&D
R&D cost % of sales (= R&D intensity)
Risk adjusted cost and the time for getting a new drug to market
Cost of R&D per ton polyolefin
R&D costs in Sales consist in the overall expense of the R&D organisation up to the prototype
R&D costs / net sales
Percentage of turnover
The cost of getting a drug to market, including the cost of all the failures along the way
The total cost of R&D to generate a patent

Total project cost for new product (start till end)
Ratio costs of R&D to turnover
The cost of R&D up to product certification (for example by Federal Aviation Administration)
R&D Cost per Revenue
Patent costs
100million euro to prototype stage
Cost of bringing product to: a) CE market approval b) FDA approval
R&D costs as % of turnover
Total cost for a new drug
Cost to develop a new product and technology up to successful market entry
R&D Costs to bring one molecule to market (including attrition)
Percent of Revenue
The cost of development period
R&D spending as fraction of sales
IP generation

The use of indicators is also sector specific (see Figure 41). As for the industry indicator, Automotive (with 26.67%) and ICT (with 36%) are above the average over all companies (16.74%), while Pharmaceuticals and Other are in line with the average (Pharmaceuticals) and strongly below (Other). As for company indicators, on the contrary, ICT (with 10%) is strongly below the average over all firms (27.70%), Other sectors harshly above (with 47%) and Automotive and Pharmaceuticals are more in line with the average. Nevertheless, the low number of observations obliges to assume these figures as merely indicative.

Figure 41: Percentage change in the R&D costs indicators over the last 5 years by industry (in %).



Source: EU Survey on Cost of Research (2011)

While in the survey we asked only for the use of specific R&D cost indicators, in the case studies we explored in more detail the question of cost control, cost management and research productivity.

Many of the companies in the case studies used the percentage of sales, net sales, or revenues to measure their R&D costs and compare them with industry norms. Some did not have formal measures of research costs but nevertheless monitored this percentage of sales indicator. Several of the companies had very detailed reporting systems to track and allocate costs (e.g. reported by Homag, DSM, and Tellabs). Stage gate approaches to create research budgets were relatively prevalent in the case studies.

Homag: the sales-R&D connection
Homag operates in the woodworking machinery industry. It does highly customized machining work. As a consequence, the company has strong ties between sales and R&D because much of its R&D work is for specific customers. At the same time, the company also needs to be able to conduct some R&D that supports to broad-based need that the company has to maintain its capabilities rather than for a particular customer. As the Homag CEO reports, *"Genuine R&D means that we develop new building blocks for our wood machinery, 'work order R&D' means the R&D costs that occur when we integrate the different building blocks and adapt , and integrate, implement them to the needs for the specific customers on his production plant on the site."* The economic downturn has affected turnover, but Homag applies modular construction principles which allows for incremental development, which helps to synchronize R&D with turnover.

Key indicators used to measure and monitor research productivity reported by the examined case studies include:

- efficiency indicators linked to adherence to milestones, deliverables etc.
- Value creation index to measure return on investment (cost focus more on industrial capital investment rather than research costs)
- research direct costs: man days, materials, real wage costs per employee, proportionate overheads etc.
- Number of patents/publications
- New products reaching the market
- Turnover generated from specific developments (often controlled by a measure of the research's proximity to the market)
- Value of research orders per product group
- Development of prices/profit margins in relation to production costs
- Development of patents in comparison to the main competitors (keeping in mind differences in patenting strategies)

Boehringer Ingelheim's IMP: documenting research output
Boehringer Ingelheim is a pharmaceutical research company that founded a non-profit research institute in 1985 to advance biomedical research. The company tracks IMP's research output. Since IMP's founding, institute researchers have authored more than 1,500 scientific papers in refereed journals. In addition, the institute have originated some 90 patent applications, which Boehringer Ingelheim has right of first use. However, because the outputs can vary from year-to-year, the institute focuses on input control *"... as the measurement of outputs is very difficult and even not meaningful."*

Many companies report that no formal measures were used to track outputs from R&D investments. Several case studies highlight the use of percentage sales from new products, sales generated from R&D projects, or turnover in the R&D pipeline. The critique of these indicators from at least one interviewee is that they are somewhat retrospective. Some companies report using formal milestones, project profitability, and net present value measures. Rhodia uses a value creation index in which capital investment in facilities and equipment is an important component because it represents a cost commitment. Other companies place greater emphasis on output measures such as publications and patents.

The case studies also illustrate that some managers do not use cost indicators; though, this does not mean that they are not concerned with efficiency and value for money. Some industries are more concerned about demonstrating impact rather than cost efficiency.

The case studies do not provide clear evidence that cost is a major concern or a focus of attention. A survey of AIRTO organisations[49] reinforces this observation (Readman 2010). The seven most important criteria used by customers for evaluating technology and innovation service providers were reported by AIRTO respondents as:

1. knowledge of specific technologies
2. quality of work
3. research capabilities
4. on-time completion
5. physical facilities
6. customer relations
7. brand name and reputation

The least important factors include offering customers the lowest price, and marketing services. Four types of RTI are included in the survey – private firms, not for profit RTIs, Government Institutions and Universities

The cases indicate that the managers were not primarily concerned by or focused on cost reduction or cost containment. Instead decisions about R&D investment are based on expected outcomes, risk and strategic competence development. There may be underlying cost related factors which are only revealed historically; for example, after a few years of working in an open innovation environment some areas of 'outsourced' R&D may be perceived as 'unaffordable'.

Cost may be a factor in many of them, yet, they only manifest itself explicitly in special and typically disruptive circumstances – e.g. when the business is downsizing.[50] At most other times cost is an underlying factor. The cases illuminate management thinking in a variety of situations that are representative of industrial R&D. This information reinforces the message that cost is not in general an important factor in directing and managing R&D.

What is revealed via the cases is that cost reduction exercises do occur in industry and are applied in R&D as in other business functions. But they are instances when the business is adjusting by various means to declining revenues, or to new innovation strategies. They are not triggered by an awareness of cumulative incremental cost increases in R&D and the actions taken are not merely responsive. Instead the adjustments that are made are often severe – departments and business divisions are closed or sold off, projects are terminated prematurely, businesses are restructured.

Nevertheless, efficiencies are seen in the extent to which innovations can be re-used. According to the Homag CEO, *"We aim to develop basic tools that in the end do not make*

[49] All are AIRTO members in the UK.

[50] From time to time businesses and public sector organisations must respond to reduced turnover or budgets. Such pressure is very different from an underlying trend in R&D costs. Reducing R&D budgets is often a relatively easy way to achieve targeted cuts, whatever their origin might be. The longer term benefits of R&D are discarded for short term gains. Essentially such cuts are volume changes; they may induce a more careful review of how and where value is added by different types of R&D activity or focus. They might also induce new ways of working in R&D – it might for example help to justify and accelerate the introduction of some laboratory automation. During such exercises cost-related innovations in R&D are likely to be considered more favourably than in 'normal' times. However, such perturbations also affect costs in other areas of business, not just R&D, and are likely to have a downward pressure on labour and management costs across the business.

individual solutions necessary, we define common interfaces and thus reduce costs of R&D and finally for the product. Here you need to co-operate with external partners". Greater integration with upstream customers and downstream supply chains enables re-use oriented efficiencies (see GDF Suez case). Fagor Electrodomesticos takes advantage of HOMTEK to enable the development of standards for kitchen technology that advance interconnections across household appliance interfaces. Motorola underscores the importance of synergies in the application of products to more than one market. Texas Instruments encourages software re-use through toolkits and model applications across product generations and business units. However, that there is a cost to the implementation of re-use approaches in that personnel transfer may be necessary and specialised management systems may be required to address complexity, customisation, and cost sensitivity in encouraging re-use and coordination of hardware and software.

The BBC case: new ways to achieve cost efficiency

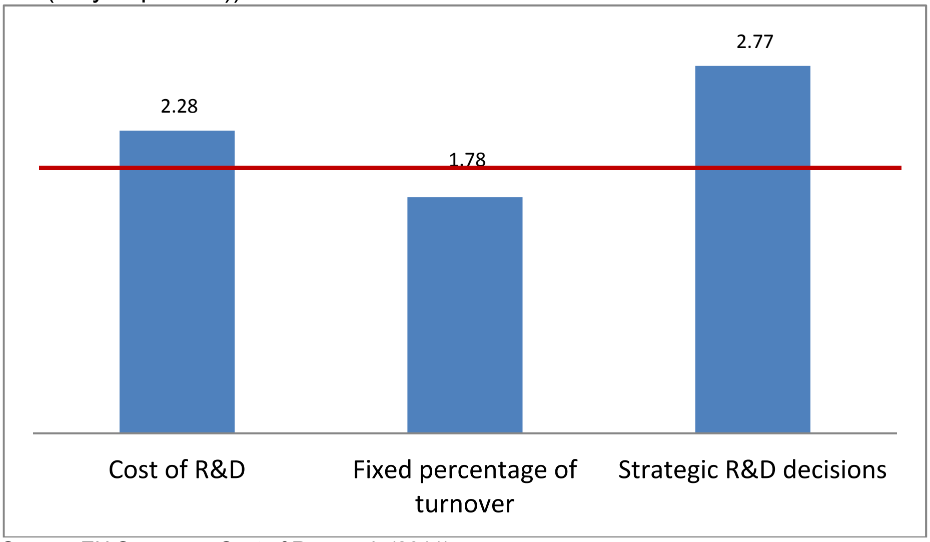
The BBC R&D case provides a very different context illustration. Like healthcare the BBC (British Broadcasting Corporation) is subject to intense public scrutiny. Unlike the pharmaceutical companies it adopts very open methods of communicating strategic decisions and sharing knowledge. Its remit is not just to develop and broadcast 'creative content' (programmes) but also to help develop the UK multimedia technology industries. Income is based on a licence fee paid in the UK by all owners of TV receivers. The level of fee is determined by government and is regarded as a tax. R&D is funded mainly from this income. The work undertaken by BBC R&D in recent years has focused on significant technological advances (including the switch from analogue to digital and the development of internet applications and content). In the 1990s it was known that R&D could be more cost-effective but what drove a major review and restructuring was a much broader analysis of the role of the BBC and how it operated. This led not just to cost efficiencies but to a radically different relationship between the BBC, its viewers, and the creative industries with which it collaborates. It operates on a very publicly open basis, (not just open innovation, but also open source) publishing via Sourceforge and other open source platforms much of its research results, and licensing much of its technology output. This licensed technology is then likely to flow back into the BBC as equipment etc. It works with hundreds of collaborators. Its objectives and performance criteria were established not to reduce the costs of R&D but to improve its impact; it has a strategic role to support innovation widely across the UK regions in the creative industries and in multimedia technology industries. R&D is a strategic investment rather than a cost; the criteria are not primarily financial but relate to the unique role of the BBC in British art and culture as expressed in its Royal Charter.

One of the major issues in management of the cost of research is whether research is considered a **strategic investment** or whether it is a cost to be managed and subject to efficiency measures. Although these are not polar positions, because many companies do both, some of the case studies interviewees emphasised one or the other position to a greater or lesser degree. Some cases stress that costs and efficiency in the research function matter. In contrast the GDF Suez case points out that R&D is seen as an investment in being an international energy leader. Cost management is less important for basic research as referenced in the Boehringer Ingelheim's IMP case. Philips indicates that R&D decisions are based on **risk management** rather than cost management. The Motorola case further suggests that research investments enable preparation for potential future disruptive changes, such as the move from analogical to digital, and that the application of extensive cost efficiencies could hamper the ability of the company to achieve returns. A further set of cases discuss the importance of balancing costs and other corporate strategic objectives. The Rhodia case points toward the importance of balancing its portfolio of key strategic technologies and competencies. Several cases (DSM, Texas Instruments) emphasize the joint strategic importance of cost management along with access to labour and market presence or innovation and market presence.

The case study reveal that business **R&D expenditure is often fixed strategically** (e.g. as a percentage of turnover, or x percent higher or lower than the preceding year, and work is then organised to a budget constraint). It can alternatively be organised by roadmapping where strategic planning determines the technologies and innovations needed by the business and the budget is allocated in order to meet these objectives within an agreed timeframe. This is clearly in line with the management literature.

The survey delivered evidence that the role of strategic decisions were considered as more important than the cost of R&D. The level of R&D is expected somewhat steered by a fixed percentage of turnover (or sales) but the total costs of R&D are also mentioned quite frequently as an important determinant of the level of R&D expenditure (see Figure 42).

Figure 42: Importance of factors determining R&D budget ((Importance from 1 (not important) – 3 (very important)).



Source: EU Survey on Cost of Research (2011)

Locational decisions are also discussed with respect to cost management. One the one hand, centralized research locations and regional spillovers are supported in the cases. For example, Bosch set up a new centre for research and advanced engineering near Stuttgart in 2009 to pool competencies and strengthen interdisciplinary collaboration. Philips likewise focuses research in the high tech campus in Eindhoven, even though it has other locations around the globe. Texas Instruments, which has global research facilities, also has added capacity at its headquarters location, through the 2008 opening of the Kilby Labs to perform proof of concept research and integrate with future revenue generating products. Boehringer Ingelheim's IMP is able to engage in cost sharing with research organisations in the same location and grants of funding support from the city government to underwrite the costs of shared facilities and databases. Ruijie Networks established R&D centres in high-tech cities in China to take advantage of the shared labour pools and deep knowledge available in these cities.

The survey in the R&D scoreboard firms shows that the **cumulative cost changes in R&D output** as writing scientific publications amounted to 15.33% higher costs, while the costs of generating a patentable application rose 20.51% during the past five years, but the costs of prototypes (or a new technological solution) rose the fastest with 23.02% (Table 24).

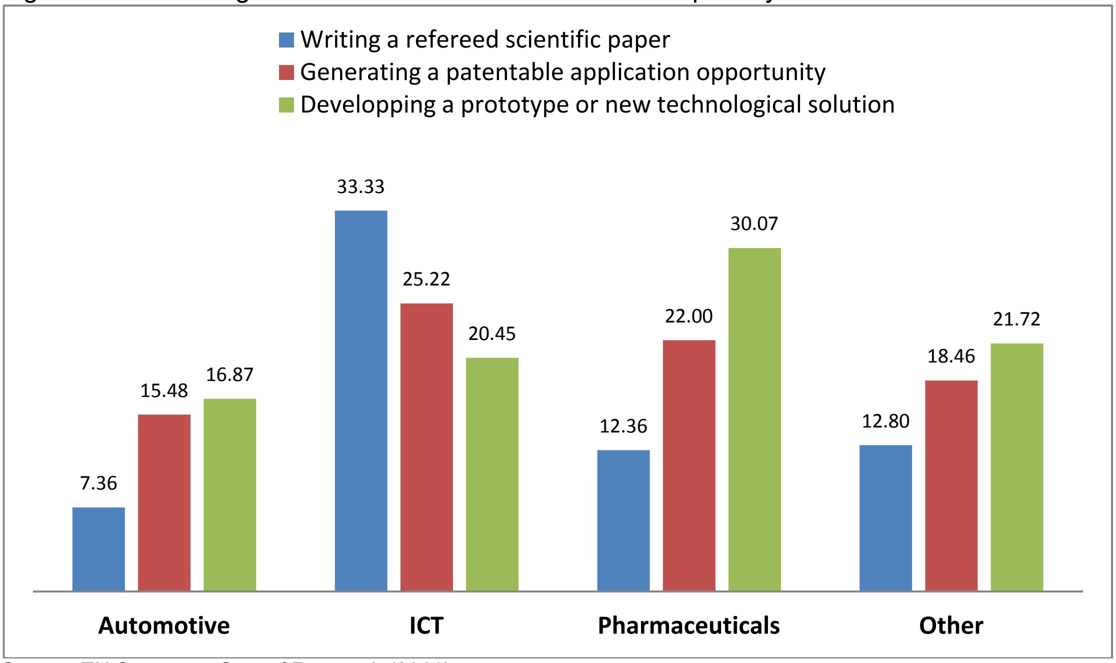
Table 24: Percentage variation of the unit cost of R&D outputs.

	% change in the past five years	N
Writing a refereed scientific paper	15.33	36
Generating a patentable application opportunity	20.51	47
Developing a prototype or new technological solution	23.02	52

Source: EU Survey on Cost of Research (2011)

Figure 43 sets out the percentage increase of the unit cost of R&D outputs by sector. On average on all firms, we have to remember that writing a refereed scientific paper increased of 15%, generating a patentable application opportunity of 20% and developing a prototype or new technological solution of 23%. Compared to these figures, the Automotive is always under the average for all outputs, the ICT is above the average for writing a paper (33%) more or less around the average for the rest, while Pharmaceuticals presents a strong increase in the cost of developing a prototype or new technological solution (+30%). Other sectors, finally present no relevant differences with the average.

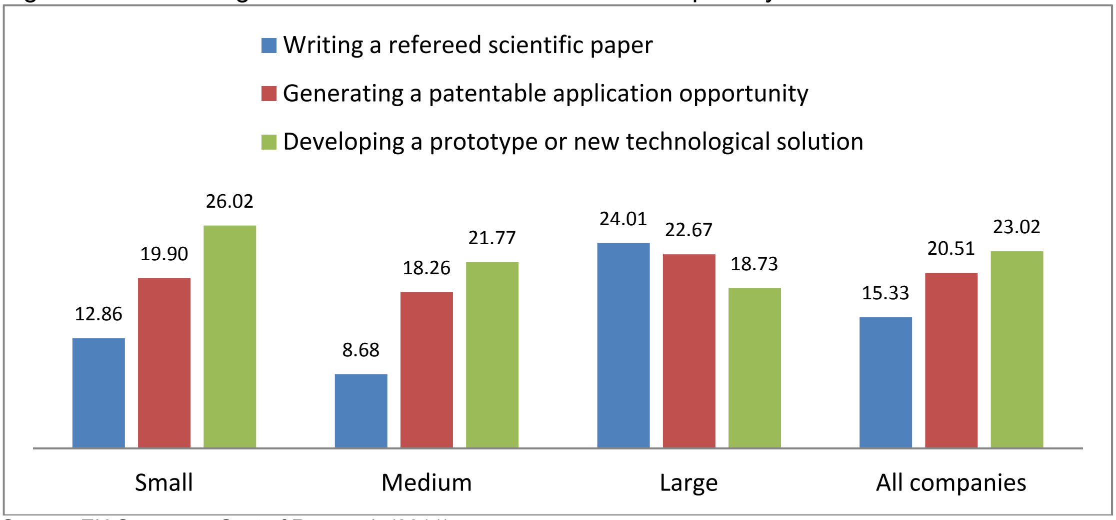
Figure 43: Percentage increase of the unit cost of R&D outputs by sector.



Source: EU Survey on Cost of Research (2011)

Figure 44 shows the percentage increase of the unit cost of R&D outputs by size. What emerges is a substantial high level of increase in developing a prototype or new technological solution for small firms (26%) compared to medium (22%) and large ones (19%), and the low level of writing a refereed scientific paper for medium firms (8.68%). Large firms, finally, follow more or less the average except the cost of writing a refereed scientific paper that is higher than the mean (24% against 15%).

Figure 44: Percentage increase of the unit cost of R&D outputs by size.



Source: EU Survey on Cost of Research (2011)

Due to the difficulties to measure the output of R&D comprehensively we are not able to assess quantitatively the development of R&D productivity. The development of unit cost per se is not delivering evidence for the development of productivity as productivity development depends on the underlying price and volume effects. However, reports about productivity trends are mixed in the case studies. Some interviewees indicate that there has been an increase in research productivity as evidenced by greater links between research and products, and more and more complex products with more sophisticated features. However, others suggest that research productivity has not grown because the rising product complexity means fewer products are turned out. Regulatory restraints on productivity especially in the biosciences industry is also noted. The economic downturn has further hampered productivity growth.

6.2.2 Public Research Organisations

Unlike companies, PROs hardly use any indicator to measure **R&D costs**: within the survey only four out of the 34 responding PROs reported the use of a cost indicator, and three have specified the following indicators: "cost of writing proposals", “ cost to generate a patent” and “the yearly hourly rate”. The other PROs either did not use any cost indicator (30 PROs) or did not respond to this question. Only few PROs specified their most important R&D cost indicator. These were: costs to write a proposal, cost to generate a patent, and yearly hourly rate.

As discussed in above, there is literature on PROs which states that cost efficiency in PROs could be mainly intended in the sense of mechanisms of coordination that “maximizes social welfare”. In this view it is relevant to look at the relation between costs and performance, intended as research productivity, ratio between scientific output and R&D expenditures, through a range of indicators of scientific outputs, such as those used in evaluation activities (publications, patents, software, spin offs). Another relevant trend is e.g.: excellence has become a relevant goal in itself.

These and the above mentioned findings of the survey are supported by the results of the case studies, as described as follows.

The accounting practices and cost control methods also differ between the types of activity conducted by the organisations. For projects which are delivered directly to a client, project accounting methods are used to monitor and control costs. For all research activities (often rather fundamental and long-term research) where basic public funds and funds from programs are used, a budgetary logic is rather dominant. This research is more open ended and it is therefore not possible to take specific returns into accounting; here then output measures (e.g. publications) are used which do not measure outputs financially. In general, PROs are mostly non-profit organisations and hence do not look for a quantitative RoI at all.

Introducing and designing the adequate **cost accounting framework** and methods is particularly challenging for PRO having **large infrastructures**. A first step is to improve internal accounting mechanisms in order to be able to fully account for and allocate costs to different activities and different beneficiaries. This is difficult for infrastructures such as a wind tunnel (e.g. CSBT). A key decision here relates to the question of whether real costs should be allocated to individual users and activities (e.g. the amortization, the energy costs etc. of the wind tunnel) or whether public good considerations are strong enough to justify the allocation of such overheads to the overall research portfolio, since a direct accounting approach would make all research using an installation like the wind tunnel extremely expensive. Thus, day-to-day cost control in relation to efficiency and/or quality of individual research activities is not possible.

Output measurement such as counting publications and patents is widely used now and helps to meet the demand for accountability, particularly for all activities that are not related to contract projects for customers. While some organisations are even publishing such performance figures there is less transparency about the inputs, i.e. the development of different resources (different cost categories). Although accounting systems have been improved and nowadays some PROs even employ the same sophisticated accounting methods such as private firms, there is still **no systematic data available to control and monitor research costs systematically**. In that sense, accounting and counting outputs is easier, although the interpretation of such figures not always trivial. In general, the outputs and success of a PRO are assessed by the position in the global scientific competition.

The scientific director of IBA, for instance, argued: *"Such numbers need a very specific analysis which we as a research institute cannot deliver at the moment. I am sure that such a list of indicators will become more and more necessary in the future because also research institutes will be managed like companies in the future. However, it is then needed to analyze such numbers carefully. For this we do not have the necessary personnel capacities at the moment. Secondly, the framework for research institutes has to be changed in a way that a company-like management of public research institutes becomes possible at all."* INRA managers, e.g., put it this way: *"As a result of the fact that INRA does not compile detailed information on the costs of research as they relate to different activities and centres, no corresponding indicators are used to measure the effectiveness or efficiency of the research undertaken."* The leadership as scientific player in its field (as illustrated in the strong ranking regarding scientific publications), is seen as an overarching sign of success."

The DLR, e.g., counts the number of publications, licences, educated students, and spin-offs to measure the quantity of its research output. It sees the proof of its high research quality in its industry assignments, as one DLR manager stated: "We still do research that is worth its money. We can learn this from the fact that we still have enough projects with the industry. They would not pay for our research if it was not worth its money."

Some PROs have started to measure **productivity** by rather simple measures of research output as described above. However, more advanced measures such as Data Envelopment Analysis are not used by managers. Performing such calculations is usually associated with the challenge to adequately measure outputs and its quality. Unfortunately, the quality of the output is hardly taken into account when conducting such productivity or efficiency analyses. Interpreting such productivity indicators has hence to be done with care. A commonly used measure is the number of publications per scientist. One PRO for instance (DLR) has set targets for the number of publications per scientist. However, an analysis of this measure reveals no clear trend.

The analysis of the development **unit cost of research in PROs** revealed that the highest growth in the unit cost of R&D regards the possibility of generating a patentable application (57%), followed by developing a prototype or new technological solution (48%) and writing a refereed scientific paper (17%) (see Table 25). This is different from the case of companies, where the highest unit cost increase was found in developing a prototype or new technological solution. This was quite expected as, compared to companies, patenting is particularly difficult to PROs, whose research activity is less market oriented, traditionally more oriented to reports, services and scientific papers, although this is increasingly changing in the last years.

Table 25: Percentage variation of the unit cost of R&D outputs in Public Research Organisations.

	% change in the past five years	N
Writing a refereed scientific paper	16.85	13
Generating a patentable application opportunity	57.14	7
Developing a prototype or new technological solution	48.57	7

Source: EU Survey on Cost of Research (2011)

Productivity: Steady or even growing?

The perception and assessment about the development of productivity varies between the respondents. Obviously, the costs have grown in the past, however, at the same time the outputs (publications, patents) have grown as well. Managers of PROs in new member states had clearly the impression of growing productivity of the research process. Although the funding of expensive equipment is challenging and wages have grown considerable as well, the catching up process and the increased demand for research by the industry gives the impression that productivity has grown. The representatives of the Scandinavian SINTEF and VTT stated that their productivities in terms of publications have grown.

Every year AIT publishes an Intellectual Capital Statement since 1999. It reports on the development of its intellectual capital aiming at measuring and reporting essential performance indicators. As an internal measurement of productivity AIT (defining productivity as output/input) uses publications in peer-reviewed journals per researcher, patents granted, and market success (external/own funding in %) as output values. As the input value AIT uses the number of researchers. Depending on the regarded output value three productivity values are derived. Each of them increased significantly during the last ten years.

DLR uses the number of publications, licences, educated students and spin-offs to measure productivity (better to say output) and argues that more intelligent research strategies, i.e. interdisciplinarity, internal co-operation and diversity, have helped to keep productivity at the same level despite growing costs: “I think productivity stayed about the same. We tried to increase co-operation, diversity, to work inter-disciplinarily in order to become more creative and innovative.”

In general, the **budget management** is a key priority in PROs rather than the control of cost per se. However, as stated above, many PROs have adapted accounting and reporting methods to be able to identify and allocate individual cost items.

From the survey we have seen that the **core R&D budget** is in 25 of the 32 cases provided by a public institution. The other seven PROs responded ‘no’ to this question, which means no core R&D budget is provided by a public institution. This finding is in line with studies showing the increasing importance of ‘programme’ based funding and the reduction in core state funding.

For the 25 PROs that have public core R&D budgets (survey results), those **budgets are determined** as follows:

- Negotiated with public owner based on strategic goals: in 19 cases;
- Based on performance agreements/contracts: in 17 cases;
- Based on performance indicators: 87.5%: in 23 cases;
- Based on size of organisation: in the case of 12 PROs;
- Other: three PROs have additionally reported another ways of budget determination and negotiation:
    - It is granted on funding allowances by the Thuringian Scientific Ministry;and
    - The performance indicators are ISI-Publication, supervised PhD students; Bachelor and Master students, lessons taught (in hours) at university (there is no link to the costs of these indicators);
    - Scientific results, success.

7 Scenarios for the future development of research costs, organisational responses and impacts for the European Economy

7.1 Overview of the process

In this chapter we present a set of scenarios to illustrate how changes in cost-related decisions about research might play out over the years ahead. Building on the analysis of the survey and case studies, we employed a **scenario method** to develop an understanding of how the identified changes might play out over the years ahead and impact on the further development of R&D activities in Europe.

Based on our empirical study and particularly the case studies we identified the drivers that are currently creating change for the cost of undertaking research in Europe. The case study material was used to identify groups of drivers for change and correlations between the individual drivers.

The first step in developing the scenarios consisted in exploring linkages between sets of drivers of the costs of research. The case study material was used to identify groups of drivers for change and correlations between the individual drivers. The case studies therefore represent the key source of evidence that informed the development of the scenarios.

The process of identifying linkages and interdependencies between drivers was helped by asking all researchers involved in the case study interviews to identify whether there was a strong, weak or no link between each pair of drivers. This helped ensure that, where a scenario related to a specific driver, the interactions with other cost drivers were picked up adequately.

One key result from the case study research related to the perspective adopted by senior executives in companies and PROs. The interviews with these executives suggested very clearly that spending on research was not primarily considered under a cost heading, but seen as an investment. In developing scenarios, this meant that the analysis and resulting narrative needed to focus on 'the cost of doing research' rather than the cost of inputs at various stages of the research process or the accumulated cost of all research activity during the innovation process.

Moreover, the case study results suggest that research is seen by the interviewed companies and PROs alike as part of the broader innovation system rather than a stand-alone activity. The drivers for change and actual changes in the cost base discussed during the interviews tended to relate to the broader strategic picture of how research is being used by different players to strengthen their position in the separate but interrelated market places for research and for innovative products. This is reflected in the discussion of driver evidence and the presentation of the scenarios.

Developments regarding the costs of individual inputs (e.g. labour, equipment, facilities) are therefore considered as a secondary element of the scenarios that seek to discuss the interactions between the strategic drivers and such cost components. Broad strategic drivers for doing research in Europe therefore provide the main structure and content for the reflection.

The high-level drivers were expressed in terms of specific management challenges that arise as a result of changes occurring in the R&D environment. This analysis was underpinned by collecting specific driver evidence to build a number of scenarios.

What are scenarios?
Scenarios are "*a tool for ordering one's perceptions about alternative future environments in which one's decisions might be played out*"[51]. Essentially, scenarios are stories or narratives that portray what might happen, why it might happen, and with what consequences. Scenarios can be very powerful tools to contemplate the range of possible futures that could develop from the influence of key drivers, events and issues. Inevitably, scenarios are developed as a range of two or three possible futures. This allows a number of possibilities and combinations of possibilities to be explored and for responses to the scenarios to be discussed and evaluated. The typical timescales applied to scenarios can vary according to the context, the use to be made of the scenarios and the planning horizon that is concerned. Scenarios can be therefore be developed to explore futures for anything from 5 years to 50 years hence.

What are the benefits of using scenarios?
Scenarios offer a non-linear and dynamic way of thinking about a problem or set of issues; they provide the ability to deal with complexity, to consider multiple variables simultaneously, and with 'different interpretation' over time. One of the major benefits of using scenarios is that they allow, and even require, a high degree of "thinking outside the box" and a way of allowing teams to consider the big, external forces that may affect their environment. Unlike quantitative forecasting approaches that seek to extrapolate the past and present into the future, scenarios carry no historical bias and allow conventional assumptions to be challenged. In many cases, therefore, scenarios are used as much for their team development benefits as for their strategic planning benefits creating a common language and understanding; encouraging working across disciplines and departments and providing the basis for a visionary element to organisational development.

How are scenarios developed?
Implementing scenarios involves careful preparation and a strong base of understanding of the key forces or drivers that may affect the macro and micro environments around the issue or context that is the focal point for the scenarios. Discussion, clarification and challenging of the forces or drivers by a group is then followed by a ranking or prioritisation. Typically the prioritisation may use criteria such 'biggest likely impact'; 'most likely' or 'most uncertain outcomes'. This discussion allows the group to agree a number of underpinning 'scenario logics' that may, in many cases, fit within a matrix (although this is not the only way of developing the scenario logics). The group is then able to explore freely, but within the parameters of the scenario logic, a 'story' that will typically involve identifying a set of 'protagonists'; the main interactions likely; any differentiating factors amongst the protagonists; the likely 'winners and 'losers' in the scenario and possible responses and strategies that may be used to deal with the story that is told in the scenario. The scenarios can then be used freely to discuss and challenge various implications surrounding the issue, the organisation or the policy area concerned and inform potential responses and strategies for the future.

The following drivers were identified from the case study research undertaken and grouped under a number of main headings:

1. Complexity of doing research

- Technological complexity
- Legislation/ regulation

51 Schwartz, P. (1996): The Art of the Long View: Planning for the Future in an Uncertain World. London.

- Market demand\ product life cycle
- Intellectual property (IP)

2. **Cost of failure**
   - Use of Stage & Gate approaches in operational management of research
   - Portfolio management – strategic management of research process
   - Collaboration – Management of research collaboration
   - Testing & modelling
3. **Relying on the right people**
   - Nurturing high skills and know-how
   - Attracting stars
   - Need for support staff
   - Staff recruitment and retention
4. **Research organisation and access**
   - Managing internal and external competencies (in-house capabilities vs. buying in)
   - Sustaining knowledge economy competitiveness (being a player)
   - Developing and implementing location strategies
5. **Cost of capital**
   - Venture capital
   - Creating shareholder value
   - Applying for and managing tax credits, grants and other public subsidies for research
   - Long-term commitment to funding for PROs

Based on these drivers and using different driver combinations as the core for each scenario, the scenarios below were developed.

The scenarios developed in this way together with the specific driver evidence (as set out below) were circulated to members of the expert group in preparation for the second expert workshop. The deliberations of the expert group focused on three main themes, namely:

- reviewing the scenario evidence,
- Identifying policy and strategy implications, and
- discussing recommendations.

The results of the expert workshop were then integrated into the final driver evidence and the scenarios as presented in this report.

7.2 Drivers evidence

These groups of drivers were identified from a analysis of the case studies, allowing a more detailed analysis to be undertaken and a nuanced description of the drivers developed.

The following sub-chapters present the results of the detailed review of evidence in the form of a narrative description of each driver, we thereby also refer explicitly to some of the investigated case study firms.

7.2.1 Complexity of doing research

This driver consists of a set of dimensions which can be described as follows:

Technological complexity:
New technological developments are rapidly changing the landscape in many scientific and industrial sectors and technology is becoming more complex. Research organisations need to be prepared to respond to disruptive change and need to be equipped to match the speed to market increasingly required to keep pace with technological developments. Indeed, the best organisations pro-actively drive change and use their controlling/driving positions to create advantage.

Depending on the technology life cycle, this impacts on cost in different ways. Large scale sea-changes that revolutionise a whole technology or product area require considerable upfront investment, but also offer considerable returns as illustrated in the recent growth in research spending in the construction industry. Having to invest consistently in the small incremental steps that are required for innovation at the end of a technology cycle on the other hand as are currently required, for instance, in aviation or oil extraction are also costly and are more difficult to capitalise upon.

As a result, many businesses and PROs are increasingly forced to invest in the soft and hard support infrastructure that enables research projects, because lacking the relevant tools reduces research productivity. Testing and demonstration facilities are a major cost factor, for instance, in the field of energy research. This is true both for ‘conventional’ energy generation with ENI spa needing to invest up to €50 million in an oil-well to test a new drilling technology and for businesses that invest in renewable energy research. The considerable uncertainty due to the pace of disruptive change in this arena has meant that a business like GDF Suez has had to invest in a number of large demonstrators in order to secure a long-term base for its core businesses as an energy utility company. This is not a new phenomenon, but the scale of the challenge has increased considerably.

The **cost of facilities and equipment** has risen sharply as a result of increasing technological complexity, most notably technology convergence, particularly the growing role of ICT in various technologies (bioinformatics). This trend is expected to carry on over the next few years. Companies need to secure access to large scale demonstrators and PROs increasingly need to invest in such infrastructures in order to be able to put their public good mission into practice. Being able to demonstrate the feasibility of new tools and approaches is a vital prerequisite for research activities in a context of increasing technological complexity.

Being able to accommodate research activities by providing the corresponding facilities and equipment is also increasingly becoming a key element in the **competition for ‘stars’ in the market for scientific researchers**. Boehringer Ingelheim, for instance, explicitly sees the recruitment of leading researchers as contingent on investment in facilities necessary to underpin excellent research.

Increasingly, product innovation also goes hand in hand with process innovation (e.g. in the chemical industry) and therefore depends on the development of new technologies to support new production processes. The overall research cost of each new product therefore increases. This trend is expected to continue into the future.

The organisational structure for research also needs to be adapted to new fault lines created by **merging technologies and new research models**. Company research activities that might previously have been organised on the basis of different disciplines, for instance, (in line with a mode 1 model of research) may now often need to be provided in relation to different product categories cutting across different disciplines and/or may need to integrate a new research paradigm that is based on co-creation (mode 2 research as introduced initially by Gibbons et al. 1994).

This plays out very differently in different technologies and product markets as well as depending on the life cycle of the respective technology and the nature of the research undertaken. In all cases, however, **businesses are having to respond to new fault lines and the restructuring process is costly.** A business like GDF Suez has structured its research function in terms of research, innovation, technical management and a Chief Technology Officer, a structure aimed at linking top-down discovery focused approach with a bottom-up identification of valuable knowledge in the field. In comparison to this, Homag, the German market leader in woodworking plant equipment and servicing, has adopted a design-led approach in order to respond to the advent of mechatronics. Its research functions are now structured in terms of product categories rather than scientific disciplines. Finally, Motorola has seen traditional fundamental research transition toward research that is more integrated with the business units and across multiple technologies to be able to influence the end products and yield higher returns on research investments in shorter time periods. This produces **a greater need for collaboration and coordination within the organisation** in order to more easily work within and across products and business units. This militates against having multiple research laboratories across the globe, although development (as opposed to research) continues to be outsourced and distributed to foreign laboratories.

Moreover, players at different points of the **research and product value chain need to ensure that they are suitably integrated in the research pipeline** in order to make sure that they are part of new technology developments. This has led to developments like the Philips internal incubator approach introduced in 2004 as part of Group Management & Services. In line with the mode 2 research paradigm it is designed to embed a market-driven approach that relies on interaction with customers and secures speed-to-market.

One response to the interdependence of different technologies is to develop standardised, **open, platform-based products in co-operation with partners**. In addition, as a result of new platform technologies becoming available, research is beginning to play a stronger role in some traditional industries such as the construction sector, which in turn leads to higher spend on research. This is a volume effect more than anything else, but needs to be recouped from the market. It also changes the competitive landscape within these sectors.

Costs are also incurred through **higher implementation and maintenance commitments for more complex products** delivered to the customer. Some manufacturers have focused effort on increasing reliability and maintainability and creating different business models in which product and service are offered as bundles with the customer in effect paying for the field support. Where such approaches are not adopted, this has the potential to eat away at margins and thus the return on investment which is a key indicator for the management of research costs.

Over and above investment in new infrastructures, the wholesale restructuring of some industries leads to lower returns from ‘sunk investment’ and the need to finance investment in restructuring. This translates into a competitive advantage for emerging economies that can ‘leap frog’ current technologies and invest in state of the art new operations.

Legislation/ regulation:

Alongside increasing technological complexity and an increasing pace of new products entering the market, legislators are seeking to act on their public protection brief by regulating the properties and uses of new technologies and products. This adds not only to the cost of individual research projects, it also **requires new test and certification processes** to be developed for each new technology. Associated investment needs to be made in the certification infrastructure supporting new products.

Apart from the absolute cost of completing research projects, this also affects the allocation of resources and leads to **a shift towards more applied research for many organisations**. For the French CSTB (Centre Scientifique et Technique du Bâtiment), for instance, this regulatory pressure on the research costs associated with each new construction application also has led to considerable constraints on CSTB's cost management approach and ultimate profitability of the portfolio of activities, since it necessitates a greater emphasis on applied research. It is only the 20% academic research undertaken for which regulatory costs are not an issue. In fact, in some areas of research activity, the regulatory requirements have boosted particular sub disciplines such as the growth in metrology in chemistry and bio sciences as reported by INRIM, the Italian national public body tasked with carrying out and promoting scientific research in metrology.

At the same time**, regulation also incentivises investment in new 'breakthrough technologies'** to respond to the new social concerns that motivate the increasing regulatory burden (e.g. environmental regulation, product market regulation). In turn, this will affect companies' and public research centres' scope to invest in a portfolio management approach. The Strategic Research Agenda for the European Aeronautics and Air Transport, for example, has shifted research investment towards a focus on finding new breakthrough technologies in order to comply with regulation. Differences in regulatory frameworks between different disciplines and industry sectors further add to the management cost of research in that setting.

At the same time such regulatory pressures translate into **a competitive advantage for businesses that do invest in adapting their products to regulatory requirements** or indeed chose to take the lead in creating new regulations, standards and platforms. The electric appliances manufacturer FAGOR sees the effect of energy efficiency regulation and the fact that now up to 60% of research investment are dedicated to this focus as translating into a competitive advantage for those European manufacturers who developed a strength in this area, a view echoed by Bosch that dedicates some 45% of its research budgets to strengthening the company's ecological orientation.

Regulation plays a particularly important role in industries like oil and gas extraction. Reducing the environmental impact by developing new technologies (both incremental and disruptive) plays a key role in the very survival of these industries.

Market demand/ product life cycle:
The increasing pace of technological change means that **product life cycles** are becoming shorter requiring more frequent demonstrators and pilot phases while at the same time unit sizes are going down. This increases the cost of research that can only be spread over smaller production runs and thus reduces the potential return on investment.

The research investment costs are predominantly incurred during the upstream activity of technology development. In some instances, however, it is the very fact that a technology is nearing its obsolescence – its 'technological frontier' – (e.g. oil extraction) that triggers high research investments in developing new systems as highlighted by Eni spa, a major integrated energy company, operating in oil and gas.

Increasing technological possibilities also shape market demand. **Customers ask for better performance of products** e.g. in respect of flexibility, productivity, energy-efficiency, safety, etc. that have research cost effects. In line with this and the increasing technological complexity of research, markets themselves are becoming more complex requiring **additional market research** with corresponding costs that need to be taken into account when calculating the return on investment from an upstream investment in research. Boehringer Ingelheim, for instance reports that the market launch as a distinct cost component in the development of a new drug has increased considerably.

However, consumer markets are not always ready to assimilate new products. In FAGOR, some of the more radical research projects are even paid for by the PR department, since the research benefits contribute to turnover and market share through strengthening the brand and image more than through direct product sales. Moreover, launching new technologies may require cooperation between competitors in order to establish a new technology in the market, as illustrated again by FAGOR's cooperation with competitors to position the induction technology in the market.

As a result, companies' strategic approach to research in response to competitive markets with constant changes in technology translates into a strong commitment to research to drive long-term growth. This is also true when considering competition with innovation dynamics in emerging markets' that puts European manufacturers under pressure to sustain or reinforce their research activities.

At the same time, maturing platform technologies in some instances reduce the need for capital investment (e.g. ICTs), because supply chain partners can increasingly be relied upon to provide certain auxiliary services (e.g. use of cloud computing and more outsourcing to generic processing, storage, and database facilities). Motorola is a case in point as it is moving toward greater use of cloud computing and more outsourcing to generic processing, storage, and database facilities.

Where this extends to the actual research effort itself, however, it bears the risk of research costs being pushed down into supply chains, either leading to efficiency losses or, conversely, benefits from specialisation and economy of scale effects within suppliers' speciality.
Where possible, modular construction principles are used to enable incremental development and extend product life cycles.

Intellectual Property (IP):
The accelerated pace of technology and product development opens up opportunities to create new opportunities as exemplified in the construction industry where new technological breakthroughs have opened up entire new product generations with associated enterprise opportunities. In this context, developing and protecting IP is at a premium.

The evidence is that **IP as a driver of research costs must be considered in two ways – protection costs and exploitation costs.** The costs of establishing adequate protection, particularly on a global basis are continually raised by research performers who seem to worry continually whether the cost of the protection is actually a good investment given the cost of then effectively taking legal action to protect the IP in different legal jurisdictions. Many note that an effective European patent would be a small but important step forward here.

At the same time, the costs of exploiting IP increase as IP generated by collaborative public-private research increases in importance. GDF Suez, for instance, referred to the cost implications from lengthy negotiation periods around the ownership and usage rights of IP developed in a collaborative research setting.

Normally of course, the additional costs should be offset by the increased returns. However, the costs involved in protecting and exploiting IP also adds to the risk associated with research and requires sophisticated portfolio management to spread such risks.

In some industries (e.g. ICT), a shift in terms of the strategic use of IP can be detected whereby IP investments are made more selectively conducting more comprehensive analyses of the IP with a view to achieving IP parity with competitors rather than gaining competitive advantage through IP. Motorola, for instance, reports that rather than developing a large portfolio of IP like in the past, the company is today more likely to focus on a smaller number of strategic patents.

7.2.2 Cost of failure

This main driver for the evolution of research cost can be described as follows:

Portfolio management – strategic management of research process:
Research decisions are made based on weighing risk vs. reward rather than on cost-management considerations. In order to remain competitive against a backdrop of increasing technological complexity and an increasing pace of change, a portfolio of key strategic technologies and an appropriate **balance between upstream research and downstream development needs to be constantly rebalanced**. The balance of that portfolio will heavily depend on the nature of the industry. An large interviewed software company, for example, comments that in software there isn't much scope for 'pure technology research' and research results need to be closely linked to application aspects and are expected to result in a product at the end.

The impact of research investment tends to be less in steady state output terms and more in terms of being able to address **discontinuities for which portfolio management is the key too**l. Particularly in industries with high societal pressure on finding breakthrough technologies (e.g. energy), companies need to invest in a diverse portfolio to be part of or even drive the discontinuity rather than being its victim. An energy utility company like GDF Suez therefore find themselves at the disruptive end of the spectrum. They need to invest in upstream discovery-led research as well as downstream technology solutions.

Finding an appropriate balance between investments in technologies that will be disruptive from an economic perspective (bringing down the cost) and those that will open up new avenues is vital and requires some form of investment in upstream research, although in many cases this will be covered by investments in partnerships and collaborative research. However, at economically difficult times, companies will reduce their spending on speculative research and focus on nearer to market research.

The **acquisition of start-up companies** with required technology capabilities is often a key component of portfolio management approaches and represent a way of buying 'ready made knowledge' rather than research. Acquisitions are not only designed to enter new markets, but are also used to increase research capabilities and have a presence in different research areas. Medtronic, the American medical device provider, for instance, has made investments worth €2.11 billion including acquisitions to enabled the company to enter new markets, increase capabilities, and add new products to pave the way for future growth.

Finally, portfolio management and strategic decisions regarding the combination of doing research in-house, outsourcing or buying in knowledge is also led by considerations regarding the multiplier effect of investments made. AVIO spa, for instance, the Italian aviation company, chose a combination of internal and external research on the basis of collaborations with SMEs and universities explicitly with the aim of reducing cost through spillover effects by levering AVIO spa's investment to trigger a larger external research investment.

For PROs this also means greater internal collaboration approaches for departments that differ in their focus, but complement technological research and development.

Collaboration – Management of research collaboration:
Co-operative research is no longer a 'nice to have', but increasingly a 'must have'. With increasing complexity of research, the whole value chain for a product needs to be integrated in the research effort. Strategic cooperation is increasingly built into the development of new technologies and products. Nurturing **strong, but diverse relationships** becomes a key investment cost in that context. This is exemplified by FAGOR; as part of the Basque cooperative Mondragon, the company has an exceptionally strong strategic partnership with the Mondragon associated research organisations to the extent that these external partners are able to specifically develop capacities necessary for FAGOR's strategic research investment areas. More recently, however, the business has diversified its partnership base considerably in order to be able to respond to new developments around health, nutrition and anthropology, all of which are domains for which new knowledge partners had to be found.

Similarly, Rhodia was instrumental in bringing about a structured and long-term Franco-Chinese collaboration in the area of 'green chemistry'. The company has had a presence in China for 30 years and operates one of its five major research centres in Shanghai. While new product development here focuses on products designed to meet the needs of Chinese consumers and industrial customers, the formalised partnership with CNRS, the French national research agency, will reduce the costs incurred in managing collaboration and will create returns for French researchers and the company itself.

In technology areas that require particularly **strong investment in demonstration facilities** (e.g. energy), **collaboration will often even involve competitors**. This makes the management of a portfolio of research collaborations and the associated IP even more important.

Shared scientific research facilities in response to increasing costs are another way of managing the increase in the cost of facilities and equipment. This often involves public and private players. For the public sector partners this has led to considerations regarding the cost model to be adopted in a climate in which PROs are increasingly expected to pay their own way.

Where standardisation of platform-based products is chosen as a response to technological complexity, co-operation with external partners is necessary in order to create a critical mass on the market and create a standardised demand from defined providers of, for instance, control technology.

However, strategic cooperation integrating the whole research value chain to ensure market focus needs to remain small enough to be manageable and produce concrete outputs. The **practical day-to-day management of research collaborations must be seen as a cost factor** in its own right. However, a business like Medtronics in the US, for instance, highlights how advances in information technology have actually led to a reduction in this type of research costs. This reduction is particularly prevalent in decreasing the cost of communication and sharing of information and documents between Medtronic and the universities and hospitals with which it collaborates.

Companies can no longer rely exclusively on their own, internal research activities to generate commercial success. While this model has traditionally given companies a degree of control over the research and innovation process, it increasingly fails to grasp the potential associated with the rapidly developing body of ideas and knowledge residing outside the immediate boundaries of the company. Here, the increasing prevalence of open innovation is relevant to an understanding of the drivers of research costs in this area.

Open innovation represents the blurring of the research and innovation boundaries between companies and their wider environments. This encompasses both the inward and outward transfer of ideas, and opens up the potential for companies to support their own research activities with IP sourced externally (e.g. patents) from other companies and entrepreneurs. It also offers the possibility for companies' unwanted IP to be commercialised through joint ventures, licensing agreements and spin-offs.

Operational management of research:

Decreasing the cost of failure is a key concern for research operations in a business context. While the notion of 'failure' is less clear cut for upstream research, operational tools to manage staged investment decisions will be used throughout the directed research supply chain. At the downstream end, one key approach to mitigating this cost is the employment of stage-gate type project management methodologies that allow research operations to kill projects that are less likely to offer a good return on investment prior to them becoming too expensive. This is used extensively by the case study companies.

Use of **stage-gate processes** can avoid the 'too expensive to fail' dilemma faced by management teams once a project has absorbed too much expense. Ensuring strong gates that are able to kill projects early is a key tool in reducing the cost of research. However, it does also require considerable management focus at the start of the research process.

Operational research management to increase research productivity is explicitly linked to 'time to market' that is required to gain competitive advantage rather than controlling cost. Tight operational research project management is identified by Homag as one key lever to speed up time to market and as a result increase turnover. Time to market is also seen as key competitive strategy vis-à-vis competitors from China.

However, return on investment is also applied increasingly stringently to ensure greater emphasis in the research function on making an impact on company products. FAGOR, for instance, reports that the need for each research project to create a considerable cash flow combined with the considerable importance of economies of scale in the electrical appliances industry means that investment decisions need to be focused as early as the strategic idea generation stage.

On the PRO side of things, SINTEF and VTT in Norway describe an increasing focus on meeting budgets and introducing more efficient research routines through better project management, although detailed cost management often tends to be handed down to individual research managers. These are expected to contribute to a strategic research agenda that is defined politically and in light of the public good mission of public research organisations. This is the case, for instance, for INRA, the French national research organisation in the field of agriculture, for the Moredun research Institute in Scotland that operates in the same field or for the Institute of Microstructure Technology at the Karlsruhe Institute of Technology. The pressure to introduce more rigorous cost accounting methods and achieve an overall cost reduction prevails in all of these institutions, however.

Testing & modelling:
Testing remains a considerable cost item in pharmaceutical and life science areas of research. The Moredun Institute, for example, reports that the cost of animal trials is on the increase, since the maintenance of farms and animals is getting more expensive and a stronger emphasis on animal welfare also drives costs up.

In some industries it is the actual input costs that drive up the cost of testing such as, for instance, in the aviation industry where the DLR sees the increasing cost of fuel and electricity impacting on the overall cost of research.

Alongside this, the pressure to predict and therefore mitigate risk in high technology research is increasingly pushing research operations to invest in modelling tools. In doing so, research operations can test the likely success of innovation without the need for prototyping and resulting expenditure. However, testing and modelling approaches often involve 3D or virtual technologies that are not cheap.

There is therefore a delicate balance between high up front expenditure with greater certainty of outcomes; versus lower up-front cost but greater risk of failure and resultant costs of many iterations/prototypes.

7.2.3 Relying on the right people

Main characteristics of these drivers can be described according to the following dimensions:

Nurturing high skills and know-how – staff recruitment and retention:
In industries where the technology content of day-to-day operations has increased, the skills profile of research staff also has to increase. **Highly skilled staff naturally come with a high price.** Rhodia, for instance, reports that the profile of research staff has changed towards a higher qualification level: *"today the group requires engineers rather than technicians"*.

At the same time, as reported by Rhodia, in Europe, careers in scientific disciplines/ technical environments are less attractive than others (e.g. IT or marketing) and often have lower earning potential. As a result, it is often difficult to recruit sufficient highly qualified staff. In addition, the DLR suggests that the number and quality of STEM graduates in Germany is declining causing recruitment issues, a trend confirmed by DSM, the Dutch chemicals company, that sees China as an important location as a high growth economy (as well as India), not only from the development perspective, but also as a source of qualified researchers in scientific fields that are "out of fashion" in the West (like organic chemistry and other disciplines).

As a result, companies will develop partnerships with academic institutions, often in emerging economies, because these provide better access and greater flexibility in terms of accessing young researchers.

However, it is not even so much recruits' skills when they join the company that matter. Companies are anxious to retain control of their know-how embedded in staff. Employment conditions are therefore important and off-shoring is not invariably the solution, since in a highly dynamic demographic and industrial environment young staff in particular is more mobile than in a European setting, being described as ‘mercenaries’ by one interviewee.

Nevertheless, being **able to purchase more research resource for the same money is a critical consideration in location decisions**. However, Boehringer Ingelheim indicates that with respect to salaries, costs cannot be controlled that easily anyway, because the market for good people is a global one where research organisations compete with China, Japan, Korea and the US. Costs for PhDs in particular are therefore largely a given.

At the same time, **wage differentials even between European countries are a key driver for researchers** themselves to make their location decision so that Elettra, a multidisciplinary Synchrotron Light Laboratory in Italy, for instance, reports that the low level of researcher salaries in Italy means that qualified personnel will often go abroad.

Moreover, considerations on know-how also impact in complex ways on location decisions. Know-how isn’t moved easily as FAGOR has found. Nurturing and retaining an appropriate level of know-how in different locations is important to achieve objectives in each location and for the group as a whole. Ultimately, this equates to carefully considering which research activity is located where and what the implications for recruiting and retaining research staff are. So even though a wage differential between the French and Spanish locations exists and the HQ is in Spain, transferring research activities from France to Spain has been hindered by the know-how factor. Similarly, Homag has taken a conscious decision to increase the number of research staff in Germany in order to secure crucial know-how in the home location.

Attracting stars:
Increasingly the costs of attracting the top, most highly skilled individuals to work on research are high. **Attracting stars involves high salaries, attractive locations and similarly competent teams.** The extent to which this is relevant to research organisations depends crucially on the nature of the research undertaken and the associated node function in knowledge networks. SINTEF in Norway, for instance, identifies international mobility as a key cost driver while VTT considers it as less important.

All of these indicate a cost to the research organisations – but one which is necessary in light of the competitive nature of the market places in which they operate as reported, for instance, by FUNDACION LABEIN TECNALIA in the Spanish Basque Country.

Alongside this, however, both FUNDACION LABEIN TECNALIA and INRA in France also highlight an issue that arises for PROs in that context; in the public research organisation arena, many PROs are formed through legislative processes that dictate salary levels and support costs. This forms a natural ‘valve’ in terms of attracting stars and allows these organisations to focus on their reputation as a key lever.

With regard to companies, while there are more graduates on the market, for companies that compete for staff at the highest levels of academic excellence and strong work performance, the pool of highly qualified candidates is in high demand, which results in elevated recruitment costs and is sometimes resolved by off-shoring research activities. As outlined, above, this is always also considered in light of considerations regarding retention and know-how.

Need for research support staff:
The profile of competencies involved in successfully conducting research is changing. On the one hand, large research infrastructures require high levels of maintenance and routine inputs

and support. At the same time, research personnel now also need the management capability associated with operating as part of networked research activities.

One way of ensuring that staff working in research facilities and equipment is used productively is to develop a full service package around the scientific use of facilities serviced by this personnel.

An alternative strategy adopted, for instance by SINTEF and VTT in Norway, is to outsource some of the costs associated with routine research support elements, such as ICT services. Outsourcing is also a key topic for the DLR in Germany that outsourced the data processing centre three years ago and is considering to outsource or share the workshops with other research centres to improve usage levels.

7.2.4 Research organisation and access

The driver expresses the following development paths:

Managing internal and external competencies (in-house capabilities vs. buying in):
An **open innovation approach does not necessarily translate into lower research investment, but rather into a different structure of such investment** (making external capacity accessible rather than nurturing in-house capacities) as highlighted above for the case of AVIO spa in Italy that actively levers the multiplier effect of working with external research organisations.

Nevertheless, co-location strategies are one way to share costs with other research performers and benefit from positive spillover effects from research activities being conducted outside of the companies or PRO. Positive spillovers can be obtained from the market for new products or processes where benefits are created for the research performers and for the population as a whole; from knowledge, the value of which becomes available for other firms and PROs; and, from a critical mass of research activities across a range of complex interrelated technologies that spills over in to the wider cluster. This also creates benefits for the network of research performers within the location or domain of interest.

The need for more diverse competencies leads particularly industry ‘specifiers’ (large manufacturers at the end of the supply chain) to stimulate the development of competences in their environment. The additional cost incurred relates to that involved in managing external co-operations and the associated pipeline of competencies. FUNDACION LABEIN TECNALIA, for example, has identified the need to invest the organisation’s agility as a key strategic priority.

The current trend towards ‘open innovation’ builds on older trends towards creating **appropriate structures to undertake and integrate research at different levels**, e.g. Boehringer Ingelheim’s creation of the Institute of Molecular Pathology as far back as 1985, which as a non-profit research institute is largely sponsored by the pharmaceutical company itself, but is fully independent in its governance and research programmes. Nevertheless, the pace, scale and scope of the move towards more agile and open approaches to levering knowledge assets and research resources is challenging research organisations’ absorption and appropriation capacities. In turn, this requires investment in staff skills and knowledge to enable research networks to operate effectively and create appropriate returns for all partners involved. In line with this, Philips suggests that an own internal research organisation that undertakes relevant research is important to be able to absorb and integrate external knowledge.

Many large companies also develop **partnerships with scientific research organisations** in order to have access to leading edge science at a different cost model. Again extending an existing pattern (e.g. Bosch traditionally working closely with research institutes and universities), investing in external expertise represents an increasingly important approach to investing in disruptive capabilities. The three-way partnership between Rhodia, the CNRS and the East China Normal University in Shanghai exemplifies the next iteration of this scenario.

At the same time, cost gains can be made through **integrating SMEs into the research supply chain** that bring niche capacity, are fast and relatively less costly. Philips has pioneered this principle in its Eindhoven campus designed to embed in-house research in a context of open innovation that enables collaboration with customers, small companies and universities.

In some industries, private companies are 'divesting' themselves of certain parts of the research infrastructure and are relying more on external resources for some of the more resource intensive tasks (e.g. laboratories). This is partly due to the greater need for flexibility in response to increasing technological complexity and partly to the economic decline in recent years. The extent of this trend being relevant to individual research performing organisations will also be influenced by the sector and respective maturity of the technology. Motorola, for example, refers to a drop in research expenditures which reflects a long-term trend in the industry as can be observed in the decline in large corporate laboratories. This heightens the need to carefully balance in-house research activities and competencies with outsourcing incl. to universities. For Motorola, open innovation is again part of the answer.

Considering the internal perspective, finding the most appropriate structure for research activities is important in ensuring productivity and as a result controlling costs. An example of a lever to be used in that respect is the size of research groups (e.g. Boehringer Ingelheim considers this an important lever to control the efficiency of the research process with between 10 and 25 group members seen as the optimal size) as well as the hierarchical structure in the research and innovation process (e.g. Philips identifies reducing the hierarchical levels in the research and innovation process as a way of improving cost and cost-efficiency, although such changes in the organisation and management of research activities are not based on cost-arguments but implications of strategic decisions).

Sustaining knowledge economy competitiveness:
For research players in the supply chain, the shift towards networked research means that they need to invest in order to remain competitive. Universities and PROs need to foster the appropriate balance between scientific strengths that large companies are not able to nurture in sufficient breadth anymore and the pre competitive research elements that these companies are increasingly looking to outsource.

Knowledge economy competitiveness of knowledge does also relate to companies' strategic approach to research in that in a competitive industry with constant changes in technology a strong commitment to research is required to drive long-term growth.

Ensuring international competitiveness of research capabilities is also important with a view to being able to access public research funding through the FPs. INRIM, the Italian national metrology research institute, for instance, decided to merge two formerly separate institutes (the Galileo Ferraris and Colonnetti institutes), which resulted in a more favourable position regarding participation in European projects. Integrating all competences in one body allows INRIM to participate in projects of a larger scale or with more important scope resulting in increased reputational benefits.

Sustaining knowledge economy competitiveness is also closely linked to investment in **research infrastructures** that in addition require recurrent expenditures in order to keep them up to date. Elettra, for instance, states that such investment peaks occur every 6-7 years, the interval at new infrastructures and the associated related additional personnel need to be acquired.

Developing and implementing location strategies:
Cost levels between emerging economies and Europe are expected to begin to level out over the years. This is the view held both by a European business like Rhodia and by the Chinese ICT manufacturer Rujie that sees China's competitive edge in high-tech manufacturing due to low labour costs diminishing. In addition, Rujie also sees the cost of materials, purchased services and capital costs increasing further eroding the cost advantage of Chinese research and manufacturing locations. Levels of inflation and exchange rate fluctuations also have an important influence on the cost differentials between different locations.

Since research investments require a longer term strategy, cost is only one of a range of factors to inform decision-making. Moreover, companies are anxious to retain sensitive know-how in their home location.

Nevertheless, cost factors do influence location choices as illustrated in Homag's opening of an research site in Poland, explicitly set up for cost reasons. However, the centre is seen as complementary to the main German location that is thereby freed up to undertake higher quality, more sophisticated work.

Many **research centres in emerging economies** are set up not so much because of their cost competitiveness, but in order to develop a presence in new markets. With a growing focus on the identification of needs to guide innovation, having a presence in different countries is also important to provide guidance for the research process to underpin innovation and speed up the innovation process. FAGOR's considerations regarding the creation of new research locations is strongly influenced by the recognition that household appliances are intimately connected with cultural expectations regarding the shape and use of a kitchen. In order to cater for such expectations appropriately, research and innovation activities need to be led by people who live in a national culture. Similarly, Philips' decision to develop China as a 'home market' was driven by strategic choices rather than cost factors.

Nevertheless, from a cost perspective, this means that additional investment in new research operations is required, both in terms of developing the necessary staff capabilities and in terms of creating the necessary infrastructure.

Investment in **joint research centres abroad** is also seen as a way to connect academics from the home country with a worldwide knowledge network and further boost collaboration. PROs are currently experimenting with different approaches to themselves developing a presence in emerging and/or low cost economies; the DLR, for instance, is actively exploring internationalisation, for instance, in the form of partnering in a significant centre for aviation currently being built up in Singapore, while SINTEF closed its Polish office in 2010, since it had not been able to obtain EEA funding or exploit the lower research costs in that location. SINTEF is now more hesitant when it comes to the idea of establishing a presence in another country which it sees as expensive and not necessarily the right tactical decision.

However, trends in terms of location strategies depend to a large extent on the **industry and technology context** and the product/technology life cycle. Where the research focus is on applying well known fundamental research across many product lines, high levels of coordination are required and strategic research functions will be more centralized (as pointed out above, for instance, in relation to Motorola's research organisational structure).

7.2.5 Cost of capital

Venture capital:
The role of investment funds in financing activities and leveraging companies' assets means that an even greater emphasis rests on ensuring suitable returns on research investments than is the case from a strategic management perspective anyway. The fact that the investment fund owners of AVIO, for instance, are leveraging the business for an 80% loan has resulted in a strong insistence on short-term focused research and a strong cost-benefit focus.

More generally speaking, a company's debt burden will influence its research choices in terms of the time horizon for a return on investment to be realised as illustrated by Rhodia adopting a shorter RoI time horizon in response to the economic difficulties encountered as a result of the restructuring process in the chemical industry.

Creating shareholder value:
Accounting rules play a role in strategic research investment decisions, since they influence the extent to which such investment creates direct shareholder value. Bosch, for instance, reports that the fact that only a small part of research costs can be capitalised due to IAS/IFRS accounting rules means that in 2009, a considerable amount has been spent on the depreciation of recognised development costs while research costs cannot be capitalised at all.

Applying for and managing tax credits, grants and other public subsidies for research:
In many industries and businesses, the use of public subsidies for research is often not linked to the direct cost of doing research, but motivated by the returns in terms of networking, vertical and horizontal consortia building, knowledge and reputation that can be realised through collaborative projects (e.g. FPs). The direct financial benefits tend to be of a small order in proportion to companies' own funding for research.

In other industries, however, finance through the FPs plays an important role for research funding, such as for instance, even some industrial companies sources between 30 and 50% of its research budget from the Framework Programmes which have invested considerable effort in improving the efficiency of managing FP-funded projects.

Minimising financial risk is another reason for using public funding for collaborative research. Participation in complex collaborative projects is also a cost factor, however, and requires existing internal capacities and critical mass to afford to go into funded, risky research projects. Finally, public subsidies can be an important element in retaining key research personnel during economically difficult periods as was the case, for instance for Rhodia recently.

Long-term commitment to PRO funding:
For PROs there is often a focus on long term research agendas and the overall outcome of the research alongside long-term funding commitments that are politically negotiated. Managing the direct input costs of research does not feature high on the agenda for

researchers who see it as a management issue instead. This can lead to high costs over the long-term for research organisations.

This is linked to an increasing focus on the productivity of the research process and a growing requirement to justify expenditure on the basis of a societal return on investment.

A number of case study PROs discussed different strategies and approaches being explored to allocate the costs of generic research activities and the investment in research infrastructure more consistently to individual research projects, both internal and external ones, and to manage costs more effectively.

Continuing public funding, however, is seen as a fundamental requirement to nurture the internal capacities within PROs that are needed to attract business from private sector clients in the first place and thus sustain a centre's role of contributing to economic development. FUNDCACION LABEIN TECNALIA, for instance, sees the technological know-how, the capacities and patents acquired with the help of public funding as creating a portfolio to cater for the needs of businesses in the Spanish Basque Country.

7.3 Main driver axes to underpin the scenarios

Through its discussion of the drivers of the costs of research based on the case studies and survey evidence and the initial scenarios drafted especially for the meeting, the Expert Group identified the strong importance of the move to a more 'open' collaborative research strategy where the costs of doing research are shifting away from the fixed infrastructure costs to transactional or relational costs associated with working with others to obtain research results.

Different sectors will move at different speeds and directions and these could be illustrated or examined but, notwithstanding this potential for variation, the main trend is toward research that is already becoming a more collaborative effort and where centralised or 'closely held' research activity is likely to be less of a 'norm'.

Therefore, the driver identified here that should be encapsulated within the final scenarios is the ***extent to which research activity has moved along this axis from 'closely held' research to 'collaborative' research.***

The second key driver identified by the Expert Group relates to a more 'systems' **based scope of research where the dominant elements within research are, on the one hand, 'science' and, on the other hand 'the market'.**

During the Expert Group discussions this was identified and discussed in the context of the human resource cost of strategies that are either about recruiting research 'stars' or alternatively are concerned with investing in the development of research teams and more flexible and broadly based research skills. The Expert Group noted that in some sectors there will continue to be a great emphasis on science as the basis for, and outcome of, research whereas in other sectors, the focus is to a much greater extent on the 'application' of the science hence requiring greater 'market' intelligence and sensitivity.

At the same time, this driver axis may be seen at work in the opportunities that are increasingly being taken to co-locate with other research performers or to re-locate close to reserves of science and technology expertise, thus gaining research performers opportunities for positive spillovers derived from investments made by others. Buying into these spillovers is an important means of managing the costs of research. At the same time, it does incur costs of a different nature, but offers more broadly based human resources or, in the case, of relocations to emerging market locations, additional cultural and market sensitivity and intelligence.

Therefore, the driver identified here and that should be encapsulated within the final scenarios is the ***extent to which research activity is driven by the quest for 'science' as opposed to the quest for 'market sensitivity and intelligence'.***

This resulted in the following grid with four scenarios:

Figure 45: The scenario grid.

Source: Own depiction

The scenarios that emerge are described in the following pages.

7.4 Four scenarios for the evolution of research costs

In the following the four scenarios are described in more detail and implications for research costs are presented.

7.4.1 Scenario 1: Portfolio builders

In response to the increasing complexity of technologies and the speed with which technologies advance and change, 'portfolio builders' have been driven to find new models for the conduct of research that maximise the chance of research success while allowing the costs of research (and failure) to be more predictable and manageable.

Portfolio builders are concerned with acquiring research results that will provide a pipeline for the exploitation of IP at many and unpredictable downstream stages and in different spheres of activity. The costs of managing their IP strategy and activities are often considerable but their results are also unpredictable.

Portfolio builders place their focus on science-driven research, the results of which allow them to be responsive to new science and technology breakthroughs and platforms. To achieve this end, they must carry out research that frequently requires significant investment costs in research programmes, skills and infrastructures.

Therefore, to manage the costs and risks attached, portfolio builders adopt sophisticated portfolio management approaches that depend crucially on a thorough understanding and effective use of strategic IP management.

While this approach provides a degree of responsiveness and flexibility, it also carries the risk of losing out in the face of new platform technologies that may not fit within the research portfolio. It is therefore crucial that research organisations balance the portfolio to be aware of, and flexible, to disruptions and 'wild cards'; otherwise the costs of failure of the research portfolio approach may prove significant.

As a result of the considerable risk/cost factors that are difficult for organisations to shoulder individually, collaborative research models, already in extensive use in many sectors, have become the norm rather than the exception. Collaboration allows PROs and Companies to spread their risk across a wider portfolio of research and science areas than they could afford with an entirely 'in-house' model of research. Research collaborations allow the sharing of costs, risks and competences to achieve research results. The management of internal and external competencies is therefore a key concern of companies and PROs. However, collaboration brings with it new types of cost such as the costs of managing relationships and partners; network costs; project management costs etc

Sustaining their own knowledge base and active research collaboration networks is a major concern for many portfolio building research organisations nervous about becoming too specialist. Consequently open innovation approaches increasing have a place providing portfolio builders with the early warning of disruptive trends and new technology developments that may be mainstreamed in the future.

At the same time, internal staff development, with attendant high costs, is essential in order to ensure that employees are capable of interfacing with global research collaborations and networks. Strong partnerships with leading academic institutions are vital to ensure access to recruit potential stars of the future at an early stage in their careers. However, the focus for portfolio builders is to nurture research teams and research team leaders capable of operating across a range of collaborations rather than create their own high status as researchers.

As leading research performers build portfolios of research activities and programmes to deal with complexity, the opportunity has emerged for niche research services providers to enter the market. Independent research service providers allow, in some sectors and contexts, higher value science-based research to stay 'in-house' while more mundane research, testing and modelling is outsourced to others. Conversely, in some industries the requirement for significant investment in modelling and demonstration activities has a reverse effect with high investment capital cost activities remaining 'in-house' but specialist research functions being outsourced to specialist providers of ancillary research services. Research-based start-up companies have seized a gap in the market for more flexible, responsive research performers able to deal with disruptive trends..

Cost implications in terms of:

- **Doing research:** *Portfolio builders* need to sustain own research activities in order to create the absorptive capacity to be able to quickly integrate external research results into their IP and innovation pipeline. However, in comparison to, for instance, the players, they will cut back on the **direct costs incurred** in equipping research facilities, direct input costs etc. in order to enable a portfolio investment approach instead.

- **Managing research:** The cost of managing research will increase further for *portfolio builders*. Complex collaborative research arrangements, particularly in a venturing context depend crucially on **IP management** practices. Often lengthy negotiations take up staff time and require considerable legal expenses.

This can be offset by investing in **partnership management**, which creates the foundation for constructive long-term relationships and more durable tacit or explicit agreements regarding the respective input costs and returns from collaborative research activities. Costs are incurred in nurturing such relationships that do not always create immediate paybacks.

Investing in **academic partnerships** in particular incurs costs in, for instance, sponsoring research chairs or supporting scholarships for relevant disciplines is and additional cost element that is likely to increase for *portfolio builders* as they seek to strengthen their presence in different countries and world regions.

Such specific collaborative research arrangements need to be underpinned by wider **network relationships**. *Portfolio builders* therefore need to invest in a continuing presence at relevant events, industry and research fora, their overall visibility through publications and contributions to the scientific discussion etc. Moreover, sophisticated soft and hard **ICT infrastructures** need to be available and corresponding cultural practices embedded in a research organisation to enable regular staff interactions with the global research community in their particular field.
Finally, these interactions and the resulting strategic positioning need to be informed by market and technology intelligence. Obtaining this intelligence is an important input cost in its own right.

- **Resourcing research:** A key input cost for *portfolio builders* relates to **staff development and retention**. Research staff needs to avail of both strong scientific and technological capabilities in order to undertake research and absorb external research results and strong research management skills in order to seamlessly integrate own research with that undertaken in partnership with other players or acquired from the wider research network.

- **Investing in research:** Finally, *portfolio builders* need to secure a stake in research being undertaken by other players. This requires venturing investment in technology start-ups and careful management of the level of commitment to technologies in different fields and stages of development in order to be able to spread risk and secure outputs in line with the evolving product and service range in the market.

7.4.2 Scenario 2: Players

A rapidly changing landscape for markets and product life cycles has resulted from increasing complexity of technology, technology convergence and the speed with which technologies advance and change. To remain competitive and relevant in a globally competitive research context, it has become vital that research performers are able to be 'players'.

Players are focused on the eventual market opportunities within which their research results are pitched. Consequently, companies have become highly responsive to changing market dynamics while PROs have been innovative and flexible. Being a 'player' in globally important research activities is now seen by research organisations as vital to staying in the game and the 'cost' of not doing so and falling behind other research organisations is potentially very high.

To 'stay in the game' and achieve their research results, companies and PROs have established research collaborations to effectively share costs, risks and competences. The management of internal and external competencies through collaboration has brought with it new types of cost such as the costs of managing relationships and partners; network costs; project management costs; etc.

A key element in being a ‘player’ is the ability to recruit, nurture and retain skilled researchers ranging from ‘research stars’ to the high quality technical support workers necessary for working in complex technologies and facilities. The cost of investing in, nurturing and retaining human resources in the research field is therefore a key issue in determining the cost of carrying out research. Consequently, the premium placed on human resource assets within the research environment and in delivering research strategies has come into sharp focus.

Turning research into successful products and processes is now the key factor for players operating in an increasing number of product markets while the technical content and complexity of technologies at work is a defining feature of growth sectors of the global economy. Highly skilled and committed human resources are required to ensure success in both of these situations. The companies, organisations and economies capable of mobilising highly skilled researchers and technicians within their research activities will be the winners in the long run. By contrast, companies and economies without the ability to mobilise research talent of a sufficiently high and flexible calibre will become losers.

The increasing use of modelling and prototyping as research tools and activities has made fixed investment in physical research infrastructures and equipment less important as the key factor of production (and cost) in research capability and capacity. At the same time, high costs are incurred to maximise the return on investment made in staff. Internal staff development is essential in order to ensure that employees are capable of interfacing with global knowledge networks. Strong partnerships with leading academic institutions are also vital to ensure access to recruit the potential high skills researchers of the future at an early stage in their careers.

Companies in particular, but increasingly PROs as well, locate their research activities where the human resources in research areas that they seek are clustered together because of culture; markets or scientific and technological specialisations. Market focused Companies establish research operations in emerging economies based on the cost differential combined with the expectation that high quality researchers will increasingly emerge from those countries.

An efficient and competitive arms-length market in research skills and services has developed to support the players. While, in the short term, this has reduced research costs as new entrants to this market seek a foothold and market share; in the medium to long term, the growing use of these services by research players is increasing demand triggering an increase in prices and research costs as the reliance of research players also increases.

Cost implications in terms of:

- **Doing research:** *Players* focus more of their research spending on their own, in-house research activities. As a result, direct input costs represent an important part of the costs incurred by these organisations. In line with the close link to market opportunities, much of this research is close to market.
  At the same time, *players* are not able to sustain the whole spectrum of research activities in-house and as a result of the increasing dependency on external research services, the cost incurred through outsourcing will increase.

- **Managing research:** Since the focus is on sustaining strong in-house research capabilities, the integration of research occurs at an earlier stage than for the *portfolio builders*. IP management is therefore slightly less prominent for *players* while the management of competencies takes centre stage.

By the same token, academic partnerships are equally important for *players* as for *portfolio builders*, but a stronger focus will rest on securing access to talent (e.g. scholarships) rather than 'owning' high level scientific research activities.

- **Resourcing research:** As for portfolio builders, **staff development and retention** is a key direct input cost for players. However, for players a stronger focus rests on technical staff with the capabilities of translating high level research results into products and services. High costs will therefore be associated with internal staff development.

- **Investing in research:** An important research investment component is associated with the need to implement locational strategies designed to provide access to talents and markets. In addition, the close alignment between research activities and product markets means that *players* need to be able to invest heavily in restructuring where disruptive change in their respective industry occurs.

7.4.3 Scenario 3: Predators

Predators are frequently found where the ability to exploit research capacity and results are the key factors in creating and maintaining a competitive position rather than the ability to generate research results. For predators, the costs of research relate to those required to stay close to the market, building awareness of and sensitivity to the market places for new products or processes and seeking out and capture spillovers from the research efforts of others.

Predators actively seek out market, knowledge and network spillovers from outside of their own organisation, scanning, often in a systematic way, the research environment and exploiting spillovers while minimising their own internal research costs. By adopting this approach, predators implicitly accept the opportunity costs that are attached because they are not doing the research themselves. They therefore accept the risk of potentially being left behind in their research domain by adopting predatory activities and buying in and buying up research talents and results.

To further mitigate against their risks and opportunity costs of 'not doing research', predators actively choose to co-locate with research performers particularly where these are also located close to important end-markets and research users. Their wider context and the environment in which the predators operate are therefore important because it is these that give them opportunities to act as predators.

By contrast with the Players who actively establish research collaborations to effectively share costs, risks and competences to achieve their research results, so Predators will allow other research performers to collaborate and share research costs while they are preparing themselves to 'pounce on' and absorb and exploit the results. This predatory activity itself has management costs.

An important aspect of the Predators activities is a focus on human resources for research, notably skilled and highly educated researcher professionals who are well networked and more broadly based in expertise and flexible in their thinking. This is vital for Predators who need the best research results identified, monitored and then exploited when they have been acquired. Consequently, predators often look for locations and contexts where the people available for recruitment and open to mobility between research organisations within a given location or sector reside.

A key element of the spillovers sought out by Predators is the range of research services that are available and that allow them to 'buy-in' specific research skills and services only when needed. In a predatory world, the costs of maintaining and developing the research services required are externalised and implicitly shared among all research service purchasers. In this predatory world the development of a market in outsourced research services has become increasingly crucial allowing the predator access to high quality external sources of research competence and capacity.

Consequent on the attractions of spillovers for predators in research, cities, regions and nations have increasingly recognised the potential power of spillovers. To help them become competitive in research they offer predators significant incentives to locate with the aim of creating or supporting spillovers. Subsidies and incentives are generally regarded as short term and unpredictable in their effect and impacts and are rarely seen as a 'winning gambit' for the authorities concerned. However, the impact of such incentives help mitigate the costs of research and particularly provide cost benefits for the location of research activities that are cost sensitive and do not involve significant fixed capital investments.

Cost implications in terms of:

- **Doing research:** Predators will keep their internal research costs to a minimum, limiting activities to translating external research results into marketable products and services.

  Just like the *players, predators* will increasingly depend on external research services so that the cost incurred through the use of entirely outsourced research activities will increase.

- **Managing research:** Obtaining market and technology intelligence is a key cost component for *predators*. Beyond direct investment in scanning and market research activities, this means that *predators* need to manage a presence in all key locations for their particular research and market areas. Where *players* and *portfolio builders* can reap the benefits of constructive partnerships, *predators* need to pay their way to research results over and above the benefits that can be derived from generic spillover effects.

- **Resourcing research:** *Predators* need to be able to pay premium recruitment costs, because they need to poach key staff from other research organisations who already avail of the necessary competencies and – crucially – networks, because they do not invest in in-house staff development. As a result, they drive up research staff costs for their whole industry.

- **Investing in research:** Similar to *players*, *predators* need to avail of a considerable 'war chest' to allow them to invest in new research-related locations quickly. However, in the *predators'* case this is not in response to restructuring, but in response to the identification of key market or other spillover opportunities. Responding to such highly mobile investment by *predators*, government agencies will make subsidies available, further reinforcing the opportunistic potential of their activities,

7.4.4 Scenario 4: Property owners

Property owners are the traditionalists of the research world. To accommodate and manage technological complexity and rapid change, property owners maintain their own research functions often with centralised research functions within their organisational structures. Property developers usually see themselves as the research 'elite' favouring the development of IP and patent portfolios with which to establish and maintain their competitive position as research-led companies and organisations.

Although Property owners understand that research is in itself a potentially disruptive activity that may significantly change their product choices and market opportunities, by building complex or centralised organisations to protect their properties they limit their ability to spot ‘weak signals’ and respond to new opportunities. This risks damaging the efficiency of research activities thus increasing costs and lowering return on investment because the creativity, innovation and flexibility of research is lost in bureaucracy and risk aversion inherent within large centralised structures.

Many Property owners deal with this situation specialising their research according to their perceived niche strengths. These strengths may relate to their product and technology portfolios; to their pre-existing IP portfolios; or to the research skills and competencies or the research infrastructures that were previously invested.

Property owners in some sectors are also dealing with considerable restructuring brought about by changes in underlying technologies, such as the chemical industry that restructured as a result of the pharmaceutical sector increasingly using biotechnology approaches rather than chemical processes. Property owners operating in these sectors face significant additional investment costs as they bring their research infrastructures, research teams and IP portfolios into line with the sometimes seismic shifts that are occurring in their technology domains.

While, increased specialisation by Property owners offer them opportunity for more precise identification of the contexts and locations positive spillovers relevant to their research effort are to be found, their focus on the creation of new knowledge driven by science and research frequently prevents them from taking these opportunities. In particular, as science driven researchers, the research teams within the Property Owners are reluctant to undermine their own research reputations and investments and competition between them to attract so-called ‘research stars’ heightens as a result. The route taken by Predators of opportunistically acquiring research results is not open to the Property Owners as a result.

Research property owners have increasingly shifted their human resource focus to the employment of the high cost ‘stars’ while defraying some of the additional salary cost incurred by outsourcing non-core or non-specialist research tasks and activities to private or public contract providers who can achieve economies of scale and shared risks across a number of research organisation clients.

Cost implications in terms of:

- **Doing research:** Property owners will have a fairly consistent research spend for most of the time, focusing on a vertically integrated R&D pipeline. Large part of the direct research cost will relate to sophisticated research facilities and inputs necessary to attract the stars (see below) while considerable resource will also need to be spent on outsourcing lower level research services to allow this high-end upstream research to be undertaken in-house.

- **Managing research:** Seeking to hold on to a centralised R&D management function increases the cost for property owners, because they are having to orchestrate all activities in their organisations and cannot rely on the self-organising benefits of flat organisations.
  In an increasingly open research environment, property owners will also have to increase their spend on protecting the IP generated through their research activities without being able to counter balance such spend with gains from incoming research results.

- **Resourcing research:** Developing a niche strength in this way relies on paying high wages to the research stars that allow bringing world class upstream research activities in-house.

- **Investing in research:** Like the *players*, *predators* need to be able to invest heavily in restructuring where disruptive change in their respective industry occurs that does not align with the niche capability that they have build their research activities around.

7.5 Policy implications

Beyond the detailed cost implications, the driver evidence and the consideration in the scenarios of how changes in the cost base might influence companies and PROs strategies point to a number of policy implications. These policy implications cannot simply be identified in terms of how costs can be reduced. Instead they need to take a more holistic perspective of understanding how cost developments and their impact on strategic choices will affect European productivity and competitiveness. The extent to which research needs to be seen as part of the wider ecosystem of research, innovation and economic performance as highlighted by the expert workshop is therefore relevant here again. This European ecosystem should however be an open system. Linkages to dynamic regions, channelling both exploiting and augmenting strategies, are of increasing importance for EU companies as well as for their ‘home-base’ systems of innovation.

Thereby, the scenarios are not forecasts about the future but should enable an informed discussion about different possible and plausible futures. As noted above, the four scenarios presented are not mutually exclusive and may be relevant for different industries and types of organisations.

The scenarios illustrate that R&D players in Europe can adopt different strategies to respond to increases in the cost of research. This relates both to an increase in the global cost of research (made up of a combination of price and volume effects) and an increase in individual cost components (e.g. demonstration facilities or managing collaborative research).

A discussion of **policy implications based on the findings of the scenarios on how companies may respond to growing research costs** in the future can be broken down into two main areas, namely a role for policy makers in overcoming market failures in terms of the nature and location of research being undertaken within the EU and its Member States on the one hand, and policy questions in relation to measures in response to a trend towards off shoring R&D to emerging economies on the other hand.

The empirical evidence illustrates that **research choices are not so much driven by the direct cost of research, but rather by an assessment of the return on investment that can be realised through different types of research**. One key issue that therefore emerges is the need for policy makers to help strengthen ways of appropriating the returns from research spending while at the same time being alert to the fact that costs must also be allocated adequately to different research activities and stages.

Allocating costs and appropriating returns from research:
At a very high level, it has become an established policy expectation in Europe that the public sector will support research with a predominantly public sector mission. The precise balance between public spending, for instance, on basic research and a private sector role in funding research at different stages of the research value creation chain differs between different Member States and over time, but the essential principle of public sector spending overcoming the public good market failure inherent in some types of research can be considered a given.

Against this backdrop, if increasing costs of undertaking research in some technology areas, industries or points in the R&D&I pipeline lead companies to chose incurring the opportunity cost from not undertaking research (i.e. adopting a predator strategy), new models of public investment in such research may need to be found. In the first instance the **policy implication here is for research policy makers to continue monitoring research cost developments and private sector responses to these so that timely policy responses** can be developed should such a scenario arise. In other words, European policy makers need to sustain a high level view of the location and nature/character of research in the wider innovation system. In the second instance, there is a role for policy makers to ensure that cost models are developed that allocate the costs of resourcing and undertaking research appropriately, i.e. as a function of the returns that can be expected to accrue to different research players.

One key component of this **is the need for increasingly complex research infrastructures and facilities.** The public sector both at Member State and EU level already plays a role in funding large scale research infrastructures (e.g. CERN) and the case study evidence clearly reveals a trend towards nurturing a different cost accounting culture and systems in PROs. This will need to be strengthened in future. At the same time, the case studies have shown that an excellent infrastructure is the prerequisite to employ excellent researchers.

By the same token, where increasing costs of research are counterbalanced by increasing returns, businesses will continue to make the strategic choice of investing in research. For this to be the case, however, **research players must be able to appropriate the returns from undertaking research.** One aspect of this is the improvement of the IP regime in the European Union. Particularly with an increasing emphasis on collaborative research, and companies reporting that IP issues can often lead to long drawn out negotiation periods, further clarifying IP issues emerges as a key policy task. Especially since purchasing R&D and Open Innovation are expected to increase.

In addition, an important policy aspect of allocating costs and appropriating returns relates to the use of subsidies and tax incentives. Further strengthening **the harmonisation of fiscal incentives for R&D in different EU Member States and discouraging any distortion of the competitive landscape within Europe** will create the necessary transparency for market mechanisms within Europe to work effectively in allocating resources to different types of research areas and stages.

Collaborative research:
The increasing complexity of research is a key driver of the cost of research. One key tool to mitigate these costs deployed by companies and PROs in this study consists in developing **collaborative research practices**. *Portfolio builders* and *players* in particular, the two scenarios that emerge as the most effective strategies to mitigate the cost of research and help strengthen the productivity of European research efforts, depend for their success on finding effective ways of undertaking collaborative research.

The literature further suggests that multi-product firms increase the willingness of managers to engage in riskier activities such as R&D and innovation, which enhance the firm's productivity (e.g. Cincera and Ravet 2011). The strong emphasis on collaborative research as expressed in the European FPs is therefore highly appropriate in nurturing the productivity of the European economy. But, the EU Framework Programme as well as other European public funded R&D programmes, could apply less severe restrictions regarding participants from Non-EU countries. In many R&D programmes it is difficult to involve or sub-contract to Non-EU partners.

However, undertaking collaborative research and specifically the transition from mode 1 collaborative research (organised along disciplinary boundaries) to mode 2 collaborative research (structured around technology/application/product areas) also represents an important cost factor. **Supporting collaborative research should therefore go hand in hand with measures to mitigate such costs by developing new structures and tools for collaborative research of this nature.** Using FP projects to nurture collaborative research skills, network management expertise, etc. may be a key way to achieve such learning and development.

Managing and mitigating the wider economic effects of hedging against risk inherent in research choices:
The need to mitigate the risks inherent in an environment that is characterised by increasing complexity drives key strategic choices on the part of companies. A key consideration in this respect is the need to balance economies of scale (as exemplified by the *property owners*) with economies of scope (as exemplified by the *portfolio builders*). Our research in line with existing literature (Cincera and Ravet 2011), suggests that diversified research and production activities prevent firms from reaping economies of scale, but increase the likelihood of benefiting from economies of scope.

While these effects are first and foremost an issue for R&D managers within companies, they also have an effect on the aggregate productivity and competitiveness of the European economy. Policy makers therefore have a duty to understand the balance and trade-offs between economies of scale and scope and to put appropriate measures in place to support adequate choices. These include supporting the development of collaborative research practices, strengthening the foresight capability and levering regulation to strengthen innovation systems.

Technology platforms also have a continuing role in helping to increase certainty for R&D players and preventing the need to manage risk from research effort to be diluted too much for economies of scope and scale to be realised.

At the same time, managing risk is an important aspect of the strategic and operational management of research within organisations. The driver evidence suggests that strategic choices tend to override operational, detailed cost management choices. However, the day-to-day operations of companies in particular will be guided by management information regarding the productivity of the R&D undertaken in-house and invested in elsewhere. While it will be important to continually monitor cost developments and their impact on strategic and operational choices, it may be counterproductive for policy makers to focus too much on measuring direct, operational research productivity. Instead, there is a role for policy to support European businesses in maximising the long-term strategic perspective on returns from R&D spending.

Levering the positive potential of market and regulatory mechanisms:
Costs associated with regulation were identified as a key driver both in the survey and in the case study research undertaken for this study. However, the evidence suggests that regulation was seen as having the potential to strengthen R&D choices and the returns on investment as well. A key requirement to reap the benefits from regulation in terms of improved returns on investment for regulation-related research consists in using regulation to stimulate research that is directed towards societal challenges while harmonising regulation across Europe.

In addition, regulation in relation to R&D and the product choices associated with such R&D needs to be aligned with trade policies and the need for European companies to realise the benefits from having invested in directed research of this kind needs to be integrated in the wider policy environment.

Positive spillovers from wider research canvas:

Investing in R&D abroad can lead to positive spillover effects in the domestic market (Castellani and Pieri 2011). From a policy perspective, it will be important to take account of such **positive productivity effects from R&D investment abroad**. It will be important to understand and monitor the dynamics of what has been described as 'home-base exploiting' vs. 'home-base augmenting' R&D strategies (Kuemmerle 1997). Particular attention needs to be paid to the effect in terms of a potential shift '*of value added activities that may outweigh positive spillovers with risks of domestic suppliers having to downsize'*.

Where companies adopt 'home-base augmenting' R&D strategies, taking advantage of lower factor costs abroad (incl. investment capital) may actually contribute to European productivity and competitiveness. In line with this, there may even be a policy role in supporting domestic companies in identifying key locations and centres of excellence in emerging economies to maximise associated productivity gains.

Fears of a possible 'hollowing out' of the innovative base of the home countries, resulting from the internationalization of R&D, cannot be confirmed. Innovative activities may be sticky and may therefore require geographical proximity with customers, competitors or own productive activities (Dunning and Lundan 2009). Moreover, the presence of knowledge complementary to that conducted at home may require a successful 'reverse technology transfer' (see next paragraph).

Absorbing research results:

Crucially, however, there is a role for policy to ensure that the necessary absorptive capacity is in place to enable the 'reverse technology transfer' (Castellani and Pieri 2011) effect. An important part of this absorptive capacity relates to the human resources necessary to underpin and deliver the R&D effort and create the link to competitive economic production. Beyond supporting European companies in maximising the benefits from establishing a collaborative presence in emerging research locations and centres of excellence, it will be equally important to enrich the European research scene with the cultural and academic impulses from emerging economies. The European research scene should be an open one and not a closed system.

Strengthening collaboration and easing the mobility and access of researchers and students from abroad will be an important lever which contributes to an integrating of cultural and market sensitivity into European research teams. By the same token, however, indigenous research talent needs to be nurtured by further promoting their careers. Enhancing the systems to endorse qualifications obtained elsewhere is an important requirement in this respect.

8 Summary of the results of the empirical study

In this chapter we summarise the findings of our study a long the four main questions of the project (see also chapter 2) formulated in co-operation with the contractor, DG Research.

8.1 Research Question 1: Past development of research costs

Whether, to what extent, and why the research costs have increased over the past two decades? For answering this question we mainly refer to the findings of the survey and the interviews in firms and PROs. As companies were not expected to provide reliable quantitative information for long term (20 year) historical trends we hence asked to make an assessment of the last 5 years.

50% of companies and 62% of PROs acknowledged that wage costs are the most important element of R&D cost. Despite this proportional representation and despite wage increases across many organisations, they are not regarded as the most significant contributor to increases in R&D cost. The survey in companies showed that in the last five years the main R&D cost increase was due to **increases in capital costs** with a total percentage change around 60%, mainly due to volume effect. Wage costs, costs for material and supplies, and other costs have grown by about 40%. However, there are also some **industry specifics** which explain some of the mentioned trends: Total R&D costs have grown particularly in the pharmaceutical sector and 'other sectors' (e.g. Machinery, Electricity, Consumer goods). In both sectors capital costs and costs of financing have grown above the average as well which was particularly pointed out as well by some interviewed managers. Costs of obtaining patents have grown especially in the pharmaceutical sector. The automotive sector reveals an extremely strong growth (97%) of cost for materials and supplies which reflects investment needs related to testing, using new materials, etc.

The survey on **PROs** reinforced the company survey and revealed that the main component of R&D cost growth over the last five years has been due to capital costs with a percentage change of 35%, due mainly to volume effect. Compared to firms, PROs spend less for capital costs and purchasing R&D. Larger and smaller PROs do not exhibit very different cost structures. Smaller PROs are more inclined to purchase R&D from third parties and their wage costs are a slightly higher proportion of the total costs.

There are also some differences regarding the size of the company: In larger companies 'other costs' are twice as high in smaller firms, probably reflecting a more complex and articulated R&D process structure in the former. However, there are too few observations in PROs to make a similar comparison.

Statistical data can be used to provide comparisons over a longer period of time but caution is needed when analyzing trends in research costs, because of differences in prices across countries. Observations derived from **R&D expenditure statistics** indicate rising R&D costs but need to be qualified. Our analysis of OECD data in the business sector for Germany, France and Japan over a longer period of time (1987 and 2005) have shown that in general the cost distribution has remained fairly stable over this longer time period. However, statistical data over such a long period bear strong limitations. As pointed out already research expenditures include volume changes as well as price changes and official statistics are unable to deliver evidence about volume and price changes. Changes in the quality, purpose, scope, output and productivity of R&D activities is hidden within an expenditure statement.

What are the most important drivers of research cost? Why do research costs appear to have been growing?

As for companies, the most important **cost triggers** that emerge are: the increasing complexity of R&D as well as policy effects carried by environmental legislation and product market legislation. Cost inhibitors are found in aligning R&D with business strategies, joining collaborative R&D projects and increase technological efficiency in the R&D process.

By sector, generally speaking, **complexity of R&D process is the most important driver of cost increase** in the present and in the past. New technological developments are rapidly changing the landscape in many scientific and industrial sectors and technology is becoming more complex. Companies and PROs need to be prepared to respond to disruptive change and need to be equipped to match the speed to market increasingly required to keep pace with technological developments. Likewise, increasing technological possibilities shape market demand and customers ask for better performance of products e.g. in respect of flexibility, productivity, energy-efficiency, safety, etc. that have research cost effects. Increasingly, product innovation also goes hand in hand with process innovation (e.g. in the chemical industry) and therefore depends on the development of new technologies to support new production processes. The overall research cost of each new product therefore increases.

The organisational structure for research also needs to be adapted to new fault lines created by **merging technologies and new research models**. Company research activities that might previously have been organised on the basis of different disciplines, for instance, (in line with a mode 1 model of research) may now often need to be provided in relation to different product categories cutting across different disciplines and/or may need to integrate a new research paradigm that is based on co-creation (mode 2 research). This plays out very differently in different technologies and product markets as well as depending on the life cycle of the respective technology and the nature of the research undertaken. In all cases, however, businesses are having to respond to new fault lines and the restructuring process is costly.

More specific **drivers on the sectoral level** based on the answers from the survey respondents are as follows: In pharmaceuticals the second most important cost triggers is the regulation of product market; for Automotive it is the environmental regulation; for ICT the scale of R&D projects. With regard to cost inhibitors, all sectors show that technological efficiency in the R&D process, collaborative R&D and aligning R&D opportunities with business strategies are most important. Here we can observe some sector specific development: for ICT collaborative R&D is in the first position, while for automotive aligning R&D with business seem comparatively more relevant.

For PROs, **increased competition among PROs and other R&D performing actors seems to drive the cost involved in applying for grants and subsidies higher and higher**, while complexity of R&D also drives cost upwards. The former driver results in increased administrative costs whilst the latter driver is focused more fundamentally on scientific and technological parameters. However, the administrative cost is one which needs to be minimised provided that doing so does not impede R&D progress. All drivers distinguished in this survey point at cost increases and this is alarming for PROs in their competition for funding (e.g. regarding competitive bidding for public funded research programmes) although information showing that all PROs were similar affected might galvanise a creative response. Moreover, For PROs, collaborations seem to be a curb to cost reduction, and it is due to the high coordination costs in EU funded projects, an aspect that

EU funding projects' managers have to take seriously into account. This aspect is also partly reflected in the high cost increase generated by applying for research grants.

8.2 Research Question 2: Expected future development of research costs

With respect to the expected future development of research costs, the company survey found that on average the total R&D costs are expected to grow by 30% over the next five years. Much higher than this average are two components: the cost of financing (around 40%) and the cost of purchased R&D services (around 50%) which are both mainly driven by a volume effect.[52] Wage costs will remain the most important element of R&D cost in the coming years.

The growing percentage change of the **cost of financing** in the next five years probably reflects the ongoing financial crisis that harshly is expected to pose also in the future more stringent constraints in the (financial institutes) provision of funds to invest in R&D. Thus, it is not surprising that an activity such as company R&D – mainly financed by cash-flow – is meant to become increasingly sensitive to potential future economic downturns, thereby raising pessimistic perspectives on the capacity of attracting cheaper financing in the upcoming years.

As for the growth of **purchased R&D**, the survey results give a picture of an R&D cost structure even more dependent on external sources. This reflects the need to cope with the increasing complexity of doing research, and to comply – more and more stringently – with the open-innovation paradigm, requiring for companies going beyond the traditional boundary of the firm R&D division and to attract and exploit those external research capabilities and competences not available in-house. **External R&D services** are expected by companies to constitute an increasing proportion of their costs which is in line with the booming role played by business services in advanced economies. These services will add value to businesses and improve R&D efficiency in several ways: customers' tastes and preferences will become more heterogeneous and sophisticated, and technological frontiers and opportunities will continue to advance.

Our analysis has shown that there are also some **differences with respect to size and sector**. As for companies' sectors, the cost component that are expected to growth more in the future are the cost of financing for Automotive, the purchased R&D services for ICT, the cost of financing for Pharmaceuticals, and capital costs for Other sectors. Hardly any differences emerge considering company size, for all small, medium and large firms, capital costs is the component that increased the most in the past (see above), while for the future it will be purchased R&D services. Thus, the same change in the R&D process paradigm is at work irrespectively of the size of the firm.

The reasons (drivers) for the future evolution of research costs are quite similar to the past development and most trends will continue and even get stronger. In particular, complexity of R&D process and environmental regulation will become more important in the future, so the expectation of the companies participating in the survey.

[52] Again it needs to be emphasised that predictions about future trends in R&D cost need to distinguish between larger volumes of activity and genuine increases in 'unit' costs. Unit costs are not properly represented by the cost of labour, equipment or capital. These can be measured and monitored as expenditures but how those expenditures are distributed and deployed is crucial and requires more detailed examination.

The picture that emerges in PROs is that there are **no significant cost inhibitors at work** according to the respondents. One would assume that all the policy related drivers help to reduce costs, but as perceived by the respondents, they did not. Although it is unlikely that for instance the coordination costs are larger than the value of the subsidy received, costs such as for applications, reporting and coordination are seen as 'cost-increasing factors', especially for the next five years. For PROs, total R&D costs will be around the half in the next five years compared with the past, and it will be due mostly to a price effect. In the future capital costs (fixed investments) will not grow as fast as in the past in PROs, while other components such as wages and materials will grow at the same level of capital (around 7%). This reflects a more balanced structure of cost increases in the future five years after a strong investment specifically in hard equipment in the past five years.

In addition, future costs need to be related to the ability to pay and the business models against which R&D expenditures are justified. Where R&D is allocated at corporate level as a percentage of turnover fixes the budget but still allows variation as turnover increases or decreases and still allows discretion between R or D or between spread and intensity of technologies and business areas. In dynamic technology areas the need to maintain an R&D presence may override other considerations. At the research end of the spectrum, costs are lower in absolute terms compared with applications development but delaying expenditures on the latter can significantly impair market success and thus reduce expected income, so trade offs between different types of R&D are not easy.

Environmental and sustainability factors – environmental legislation was considered as most important cost driver (in the past and future) – will increasingly become even more important and create new business opportunities and markets for R&D (and its accumulated expertise or capability) in the future. These factors do not need to be regarded as incurring cost penalties but as integral. 75% of R&D budgets in aerospace can now be allocated to emissions and fuel consumption.

With respect to environmental legislation as driver of research costs one may also refer to the challenges caused by **climate change**. Climate change is likely to be a major factor that alters the economic environment in which firms operate. It may well prove to be somewhat akin to globalisation: a slow, but powerful and inexorable force that progressively changes relative prices, relative costs, structures of demand, and hence the structure of production. Climate change does not only impose costs on companies, however, it also presents considerable opportunities. Technological innovations may not only reduce emissions of carbon, but lead to firms becoming more efficient in the use of all inputs, boosting net profit. Sectors which may benefit particularly from new technological opportunities include: automobiles, utilities, integrated oil and gas, and chemicals. For example in automobiles, the main domains in which innovation is likely to be needed include cutting the emission of pollutants and CO_2, reduction of fuel consumption, and development of the use of renewable energies. The firms that will prosper are most likely to be those that are early to recognise the importance and inexorability of climate change, foresee at least some of the implications for their industry, and take appropriate steps, including R&D investments, well in advance.[53]

[53] During the last five years, BMW, for instance, has clocked up annual R&D costs of about 2,300 euros ($3,200; £1,600) per car, compared with 1,700 euros spent by Mercedes and 1,800 euros spent by Audi. Much of the money has gone into the carmaker's Efficient Dynamics programme aimed at making engines more efficient, improve aerodynamics, reduce weight and capture energy during braking (Interview with Norbert Reithofer, CEO and Chairman of the BMW Group management board, 2007).

Balancing the costs R&D in an effort to cut CO_2 emissions is a finely judged decision, especially when profits are concerned. Analysts still say BMW – which at one point was more profitable than Ford, VW and Renault combined – now struggles to earn profits proportionate to development costs (http://www.europeanceo.com/profiles/norbert-reithofer-bmw).

8.3 Research Question 3: Strategies to deal with increasing research costs

With respect to managerial strategies to cope with growing research costs, the company survey found that improving **worker productivity** and **collaborative networks** were regarded as most important to address the challenge of increasing research cost.

Improving worker productivity may be realised through a number of managerial activities: One way of ensuring that staff working in research facilities are used productively is to develop full service packages around the scientific use of facilities and thus use the facilities themselves and the staff delivering such services to their full potential. The notion of worker productivity thus relates more to activity levels rather than faster working.

Collaboration is the second most important strategy for companies and PROs to contain costs. It is manifest in various forms which can all be included under the umbrella term 'open innovation'. Although there may be additional administration costs and inefficiencies associated with collaboration, it is considered the least important factor to increase costs. This is because the benefits far outweigh the costs. It facilitates specialisation which allows risk to be shared, equipment to be shared and expertise to become flexible and virtual. These benefits extend over many years to the preparation and maintenance of R&D capability in specific competence areas which need only to be accessed for short periods. Collaboration thus extends and merges with networking and the evolution of more efficient knowledge eco-systems, into the growth of R&D based services and the creation of new business models for R&D and new types of businesses.

Technology and innovation requirements reinforce the need for collaboration. There is an increasing need for multidisciplinary projects and the fusion of technologies and research strategies (e.g. bioinformatics and electro-mechanical). It also requires new interfaces between R&D and other functions in an organisation such as marketing, sales, design, strategy, etc. and similarly with other organisations in the value chain.[54] Some companies achieve this via strategic partnerships with (several) universities. Some do it via venture capital investments and the acquisition of technology businesses. Others might do it by focusing R&D on innovation objectives instead of scientific objectives. The latter is a recent development by Motorola, somewhat countering and perhaps providing a weak signal for future trends; it has closed a number of research laboratories around the globe with distinct scientific expertise to encourage closer integration and a focus on innovation outcomes.

Although major corporations have seriously embraced open innovation philosophies, and although many **EC funded projects** have depended on collaborative projects, there are some scholars who think that collaboration will be associated with higher (transaction) costs, diminishing the attractiveness of such a strategy. Concerns about losing expertise in areas of core competence reinforce this scepticism. But collaborative R&D and the increase of purchasing R&D (driven by a need for R&D specialisation) shares the risk and cost of learning to each company; options-thinking and learning company (Burgoyne, Pedler) or learning organisation (Senge) concepts facilitate more creative ways of justifying and exploiting R&D via collaboration.[55]

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[54] This is strongly evident in the model adopted by the above presented BBC case – it expects to stimulate and facilitate innovation in multimedia technology industries so that the UK industry benefits and the eco-cycle returns benefits via open source methods and standards to BBC production.

[55] Fundamental world view scenarios can be invoked; if we wish to live or if we believe that (business and regional) competition will increase then closed (secretive) strategies will prevail. If we think that cooperation is desirable then using and organising R&D as a gateway to access globally available and distributed ideas, opportunities, technologies and research knowledge is more likely. Trends in general (including open-source, internet, social media systems and 'cloud computing' as well as open innovation technology markets and problem-solving

Although collaborative research has its own rewards as indicated above (sharing technological risk), **companies will take advantage of public funding to further minimise their costs.** EU projects have coincidental advantages, offering opportunities to do projects with new partners and to engage with 'unlikely' partners in new fields. They also provide incentives to enter entirely new research fields in the pre-competitive arena. Minimising the perceived financial risk and the barriers to entry or perceived affordability are subtly different motivations from a cost-reduction motivation. The schemes may in fact cause increased expenditures, inducing activity that would otherwise not be undertaken.[56] When the outcomes of research are not closely specified the justification to engage in that research is more difficult; what is needed therefore is either creative strategic justification (which foresight methods might facilitate) or tangential learning benefits. Moreover, projects involving standards were considered as useful, which was also stressed by an interviewed US firm.

Of particular interest is that expanding R&D activity to low cost countries was considered as least important to contain research costs. In any case, salary inflation has been detected in India and China. As international R&D centres become established as part of the cost structure they simply become locations where costs can increase. Relocating to even lower cost countries is not a sustainable or practical strategy. It is not therefore surprising that **'offshoring' R&D** is undertaken for reasons other than to reduce R&D costs. Strategic factors related to R&D and innovation capabilities are more likely to be the influence (e.g. Phene and Almeida 2008; Belderbos et al. 2009). In PROs, the expansion or relocation of R&D activity to low cost countries has over the past 5 years not been an important factor at all. In any case the development and maintenance of R&D capability within a particular region can be part of its raison d'etre. It is more likely that PROs might internationalise in order to secure contracts in a wider range of markets, both in advanced and emerging economies.

Concerning the increasing share of R&D of EU firms that is performed in the most dynamic growth regions both the **knowledge augmenting and exploitation arguments** play a role. However, market- or demand driven innovation arguments appear to be more important than R&D supply- or cost-driven arguments.

Gaining access to **public R&D funds is not considered a motivation to set up international R&D centres** but may influence precise locations within a targeted country. Tax credits might directly influence the retention of an R&D centre when a company is consolidating or restructuring but in normal times the more significant effect of tax credits will be to nurture the science and innovation culture and hence attractiveness of the region/country.

R&D management strategies for PROs reveal almost the same pattern as found in companies. In parallel with companies the importance of worker productivity and collaborative networks is obvious while much less and declining- importance is attached to expanding R&D activity to low cost counties, outsourcing of R&D and the acquisition of new companies. A number of case study PROs discussed different strategies and approaches being explored to allocate the costs of generic research activities and the **investment in research infrastructure** more consistently to individual research projects, both internal and external

competitions) suggest that the latter (open, cooperative) system of R&D is more likely. As such systems emerge the basis of measuring and understanding 'costs' must evolve. What might be regarded as a cost is simultaneously an entrepreneurial opportunity.

[56] A simple analogy is the effect of a retail sale on consumer purchasing behaviour – sales can reduce the cost of necessary immediate planned purchases but increase overall spending when taking into account impulse and optional purchases.

ones, and to manage costs more effectively. This is linked to an increasing focus on the productivity of the research process and a growing requirement to justify expenditure on the basis of a societal return on investment.

Whilst applying for **subsidies and exploiting tax incentives** is not seen as a strategy to contain costs, public subsidies can be an important element in decisions to retain key research personnel during economically difficult periods. There is recent case evidence on this, for instance, documented by Rhodia and Philips.

The empirical study delivered also **evidence for three specific hypotheses** we have proposed based on the theoretical literature explaining the relationship of specific drivers, costs and organisational strategies (see chapter 4.1.9). We indeed found that collaboration and location strategies are important to manage and contain the costs of research (Hypothesis 3). Moreover, a number of case studies delivered evidence which support the argument, that companies either strive for excellent research at higher costs or routinised, less complex research with lower costs (Hypothesis 1). Finally, strategic factors appear indeed to be more important in R&D decision making than cost factors, particular when the technological complexity is very high (Hypothesis 2).

The interviews with the executives suggested very clearly that spending on research was not primarily considered under a cost heading, but seen as an **investment**. This means that the analysis and resulting narrative needed to focus on 'the cost of doing research' rather than the cost of inputs at various stages of the research process or the accumulated cost of all research activity during the innovation process. It is this heightened need to take advantage of multiple technological developments at any one point in time that also puts research collaboration and portfolio management approaches at a premium.

This does not of course mean that R&D managers, or scientists and technologists working in R&D, can be profligate. It means that the **intelligent focusing of R&D can have a much greater effect on the value and impact of R&D on the business than cost reduction within the R&D department.** It also means that reducing the risks associated with R&D investment and reducing the cost of failure by deciding more wisely 'what to do' is more important than just reducing the cost of 'how to do it' on what is already in progress. Creativity and uncertainty make it more difficult to measure R&D efficiency and more desirable to focus on R&D effectiveness and impact.

Thus, to conclude, **cost does not appear to be a key factor in directing and managing R&D;** this is not a surprising observation but it is complex and needs to be stated precisely: It does not mean that managers are not concerned with cost; research costs are a factor in many firms, however, they are becoming mostly significant in special and typically disruptive circumstances – e.g. when the business is downsizing.

Finally, **new ways of financing research**, via internal and external venture capital, new **business models and services** are relevant and will become more important in the future. New ways of focusing research are possible. Suggestions currently being made for pharmaceuticals and how the BBC is actively promoting new levels of engagement between R&D and supporting industries illustrate this point. Perceiving innovation opportunities as services and experiences instead of just new products can stimulate the identification of new types and foci for R&D and coupled with trends in (R&D) services provision (and the emergence of R&D as an industry) will lead to a sophisticated 'interactive fragmentation' of R&D activity (analogous perhaps to the emergence of cloud computing in IT). This will make it more difficult to analyse expenditure statistics as currently collected in scoreboards and more necessary, for policy but not necessarily for business or PRO management, to understand cumulative project and learning costs.

8.4 Research Question 4: Impacts for productivity and competitiveness

The findings of the survey regarding the unit costs of research revealed that **cumulative cost changes in R&D output** as writing scientific publications amounted to 15.3% higher costs, while the costs of generating a patentable application rose 20.5% during the past five years, but the costs of prototypes (or a new technological solution) rose the fastest with 23.0%.

However, companies had hard times to assess the development of productivity of research over the past and its likely development in the years to come. The perception and assessment about the **development of productivity** varies between the respondents. Obviously, the costs have grown in the past, however, at the same time the outputs (publications, patents) have grown as well although it is difficult to assess the quality of the output. Generally, from the managerial perspective, companies put more emphasis to raise the output of R&D (output control) and to a lesser extent aim to raise productivity by reducing costs (input control).[57]

Within the survey we have not collected data about the development of productivity which is difficult due to the different R&D outputs and its measurement. In this context, the cost increases of the last five years of those companies who reported that research costs have mainly grown due to prices was about 23%, which is, interestingly, about the same growth rate as the unit costs development of producing a new technological solution (23%), however, more information would be needed to assess the development of productivity levels.

Reports about productivity trends are mixed in the case studies. Some interviewees indicate that there has been an increase in research productivity as evidenced by greater links between research and products, and more and more complex products with more sophisticated features. However, others suggest that research productivity has not grown because the rising product complexity means fewer products are turned out. Regulatory restraints on productivity is also noted especially in the biosciences industry The economic downturn has further hampered productivity growth.

Managers of PROs in new member states had clearly the impression of growing productivity of the research process. Although the funding of expensive equipment is challenging and wages have grown considerable as well, the catching up process and the increased demand for research by the industry gives the impression that productivity has grown. The representatives of the Scandinavian SINTEF and VTT stated that their productivities in terms of publications have grown.

8.5 Further lessons and implications

When interpreting our findings the limitations of the empirical study have to be taken into account. The sample in this survey is a representative sample with regard to sectors of industry in Europe, it is not representative for sectors at a global scale. It does not recognise the collective importance of SME R&D effort, or the trends towards distributed R&D and open innovation.

[57] The distinction between input- and output control is an important one within the management literature (e.g. Hofstede 1981, Leitner and Warden 2005).

Investigating research costs has to take the quality of the research output into account. Investigating research cost has to take into account the difference between pure price developments and changes in quantities: one cannot study cost of research without researching both inputs as well as outputs of the research process. The nature of the research process itself and the difference between basic research and applied research as well as the emergence of breakthrough technologies which can start entirely new research strands greatly complicate matters. This implies that contextual differences are highly important apart from pure cost aspects. The nature of the research process, the size and structure of final goods market, the maturity of the technological base, institutional factors, collaboration with universities and other (semi-public) research institutions, quality of research labour and research infrastructures all are highly important aspects of the research process and of the cost of research.

Based on our work it is possible to distinguish several definitions and interpretation of research costs:

1. R&D costs can be regarded as **business expenditure on R&D**. This is a valid measure in the sense that it is what has actually been spent on a range of R&D activities relevant to the business but measuring expenditures does not provide information on price or volume of any of the inputs. This measure also fails to record that the needs of a business evolve and that the volume and type of input changes accordingly.[58] Business expenditure aggregates total R&D expenditure across all business areas in the corporate group, across all phases of the R-D-I process and includes work for emerging technologies, radical innovation and incremental innovation. It does not fully recognize technological dependencies on collaborative companies and companies in the supply-chain (or value chain). Neither does it distinguish preparatory and anticipatory R&D costs (learning and experience) from contemporary projects.[59]

2. R&D costs can be measured using the concept of a **unit cost** (of input). This approach has been adopted in this study and is also referred to as the “price-per-unit-research-times-volume” approach, because it allows to distinguish a price and volume effect for the concerning research units. Based on a breakdown of cost components of research such as labour, capital, management, financing, etc. our approach enables to compare trends over time and across sectors.

3. R&D costs can be measured in terms of **unit cost of output**. However, it is difficult to measure outputs from research since the ‘units’ of knowledge, ideas and information are intangible, although publications and patents might be used as a proxy (as done in our study as well). However the use of such proxies is often to determine the productivity or effectiveness of R&D – i.e. how well the inputs have been utilised.

[58] In addition, business expenditure on R&D typically involves several or many projects and can range across diverse technology areas (micro, nano, bio, etc.) according to the needs of different business divisions. This can obscure both: (a) changes in the cost of R&D in particular technologies and (b) the cost of entering a new technology area (a very important reason for conducting R&D and an important focus of attention for policy design).

[59] In addition R&D expenditures in companies represent strategic decisions and implicit assumptions about the business model as well as shareholder expectations. This is illuminated by Haours (2004) in The Innovation Paradox. R&D funding might be allocated on rules of thumb or industry norms such as a percentage of turnover. As business grows or recedes, the fortunes of R&D departments follows suit. Major adjustments in expenditure tend to happen when restructuring, acquisitions, divestments, and business reengineering or simplification exercises are undertaken. In other words the R&D allocation is discretionary rather than representative of actual costs, R&D managers seek to organize as much as they can within the available finance, recognizing that the knowledge, skills, competences and insights to perform well in R&D are not acquired instantly (but can be destroyed instantly).

Innovations such as improved products and processes may arise but these are difficult to quantify and depend on other business factors such as marketing and production, not just R&D capability.

4. R&D can be measured as a **project cost** (i.e. allocated to a specific objective over the lifetime of that project). Projects can be internal, external or collaborative. Projects might last several weeks, months or years. Problems solved for one project might (immediately or eventually) benefit work on another project. Unit costs such as labour could be charged to a sponsor instead of a single project; this might be more useful in research than development and to encourage the cross-fertilisation of ideas and knowledge across projects. Costs measured in this way are more indicative of technology foci and knowledge domains.

5. R&D costs can be measured as **total cost of R&D within an innovation project**. Projects can be represented by a (innovation) lifecycle curve with variations in effort intensity over the duration of the project. A project might be an R&D project or an innovation project with several associated R&D requirements. A new drug for example is an innovation which needs different kinds of R&D for discovery, development and testing. Peaks and troughs in the intensity and scale of R&D effort might be illuminated and this would emphasise the flexibility of the virtual resource available via open innovation methods.

6. R&D costs can be estimated as the cost of **delivering a specified service** to a client organisation (similar to project cost). Because there is a commercial transaction there will also be a negotiated price, above or below the actual cost. This might make the apparent cost more precise to the client (it will be the price paid) but to the supplier there is still an element of flexibility (within accounting protocols and contract law etc). For policy purposes it might be accurate enough to ignore this flexibility just to observe longer term trends.

The above cost categories have different interpretations and uses according to the context in which information will be used: public sector, corporate management or policy advice.

To conclude, in this study "costs of research" was investigated in a particular way, namely defining costs of research as "price per unit research times volume", which is different from the classical Frascati R&D business expenditure approach. The “price-per-unit-research-times-volume” approach has several advantages over other approaches:

- it is a data-based, factual approach that allows to verify statements like "research costs are on the increase";
- it enables a detailed breakdown into all cost components such as labour, capital, management, financing, etc.;
- it allows for comparisons over time and across sectors;
- it helps in structuring predictions for the future.

Our study indicates also further questions which should be addressed by future research studies:

- Firstly, studies may further split up or differentiate cost elements (e.g. labour costs) to get a better evidence for the evolution of research costs.

- Secondly, the frontiers of research are continuously advancing as a result of new equipment and computing applications, accumulated knowledge, scientific opportunities and emerging technologies, changes in management methods, R&D

locations, etc. The role of such factors should be studied in more depth aiming to identify drivers, organisational responses and its impact on R&D efficiency and effectiveness.

- Thirdly, future studies should combine cost and performance data to get a richer evidence about research productivity and links with economic performance. Moreover, R&D could be disentangled by its composition: by various stage of research pipeline, but it could be also possible to identify cost and performance within a firm's portfolio of R&D projects.

- Fourthly, while we have focused on large firms and PROs, it would be of interest to investigate (and compare) the evolution of research costs in smaller firms, start-ups, universities and other public and semi-public research performers.

- Fifthly, data about volume and price developments from secondary or statistical data (e.g. price for a specific equipment, development of wages) might be used as complementary source to analyse the evolution of research costs.

Apart from those specific research questions we found that the topic of the evolution of research costs, its drivers and impacts has not gained much attention in the theoretical literature so far, neither in economics, management, and accounting literature. Different theoretical approach and disciplines should hence be used, integrated and elaborated to propose and test systematically the relationship between cost drivers, managerial strategies and the impacts on productivity and performance. Our proposed conceptual framework and definition of research costs serves as starting point for such an endeavour.

8.6 Conclusions for European research policy

How can policy influence the research process in companies and PROs taking into account the challenges that are posed by rising research costs? Answering this question requires first of all a generic view of the entire R&D process and its context. This includes considering business strategies, R&D and innovation strategies, the roles of PROs in knowledge and technology 'eco-systems', and the attractiveness of R&D jobs and working environments. Policy implications cannot simply be identified to address a need for cost-reduction. Instead a holistic perspective should be adopted to understand clearly how cost trends and underlying factors impact on the strategic options of all stakeholders. Good strategic decisions will significantly affect European productivity and competitiveness. In addition R&D itself is a growing industry.

The findings of the study offer the following specific conclusions related to some recent policies debated on the European level:

1. Focus policy on appropriating and absorbing returns from research done locally and globally

The empirical study has shown that locational advantages in different host countries give a critical incentive for the firm to replace domestic R&D by activities abroad. However, these locational advantages are not mainly lower labour costs but other factors such as closeness to markets, linkages with universities, etc. Thus, the increasing amount of R&D expenditures by EU firms in China and India is not motivated by cost advantages, but by market opportunity and user-driven considerations. One key policy issue that emerges from a more geographically dispersed R&D is to strengthen the ways of appropriating the returns from research spending while at the same time being alert to the fact that costs must also be allocated adequately to different research activities and stages. In addition, policy should support global firms to exploit positive spillover effects from R&D done in non-European regions and to enable the reverse technology transfer.

For this to be the case, however, research players must be able to appropriate the returns from undertaking research. One aspect of this is the improvement of the IP regime in the European Union. Particularly with an increasing emphasis on collaborative research, and companies reporting that IP issues can often lead to long drawn out negotiation periods, further clarifying IP issues emerges as a key policy task. Moreover, the survey and interviews have shown that purchasing R&D and adopting Open Innovation strategies will increase further.

Also for PROs and SMEs the internationalisation strategies of 'exploiting' or 'augmenting' can be relevant. Innovation policy instruments to support the internationalisation of companies[60] (and research organisations), but also the Lead Market initiatives are especially supporting the 'exploitation' aspect. Arguments of 'home-base-augmenting' can be found in public research programmes, where for instance sub-contracting to foreign or non-EU organisations, is only allowed when the concerning knowledge is not available in the national or EU 'home-base'. Promoting international cooperation between PROs and Joint Programming are relevant in this respect[61]. Most PROs in Europe are however still national research labs; truly European Public Research organisations hardly exist yet.

In addition, policy should support global firms to exploit positive spillover effects from R&D done in non-European regions and to enable the reverse technology transfer. Less restrictions for the involvement (e.g. regarding sub-contracting) of non-EU parties in National or EU R&D programmes (including FP) is also important. Inviting them to be part of European research networks, may even persuade non-EU organisations to locate more R&D in the EU. The European Research Area and the Innovation Union[62] should therefore be an area 'open' to non-European actors, and not turn it into a 'Fortress Europe' (Soete, 2008)[63]. While companies increasingly have addressed the 'not-invented-here' syndrome of the past, and are aware that they do not have to generate all knowledge themselves, national and EU policymakers should also adopt a more open innovation paradigm and secure the inclusion of EU locations in global R&D networks.

2. Attract and educate research talent

Labour costs are a central component of the costs of research. Increasing labour productivity was considered as highly important by companies and PROs. Policy should hence create conditions that companies can recruit highly qualified researchers and attract the best talents for R&D. Some companies articulated a shortage of qualified researchers, although this was rather a problem in specific sectors and for PROs. Policy makers in Europe should focus on maintaining a high standard in the education of researchers, and improve the framework

60 See: Sandred, J., Kiper, M., Ipektsidis, B., Kamp, B. (2009): International aspects of support to innovation. PRO INNO Europe, Mini-study of the INNO Learning Platform. Brussels, http://www.proinno-europe.eu/admin/uploaded_documents/Mini-study_8-final.pdf

61 Nauwelaers, C. and Wintjes, R. (2009): Monitoring progress towards the ERA (European Research Area), Report for the IPTS, European Commission, Seville, March.

62 EC (2010) Innovation Union, COM 546 final. Brussels: European Commission, 6 October. See: http://ec.europa.eu/innovation-union

63 Soete, L. (2008): Innovation Policy in a post-Lisbon Europe; some reflections, In: Nauwelaers, C. and Wintjes, R. (eds.) (2008), "Innovation Policy in Europe; Measurement and Strategy". Edward Elgar: Cheltenham.

conditions that attract high quality organisations and high quality (justifying high salary) researchers.

Researchers' education also has to deal more extensively with grand challenges, international mobility, entrepreneurship, and interdisciplinary research and hence universities should adapt their curricula. With respect to the above mentioned requirement to strengthening international collaborations easing **the mobility of and access to researchers and students from abroad** will be an important lever in integrating the cultural and market sensitivity into European research teams.

Human capital development is also related to the development of the structural capital, i.e. investment in research equipment and facilities. Particularly PROs but also industrial firms in some sectors were concerned about the rising cost for infrastructure and equipment. However, infrastructure is a necessity and attract for excellent research and to recruit excellent researchers, which, in turn, contributes to the effectiveness of R&D.

3. Foster collaborative research by minimizing transaction costs

Currently and in the future we see a shift towards strategic R&D networks and open innovation: overall companies are performing less research in-house and are accessing, outsourcing or collaborating outside the firm, and outside the EU15. More so than reducing their costs, this reduces their risk and exposure in basic research, expands their virtual or apparent capability, and simultaneously facilitates specialisation in R&D capability. These benefits combine. More collaboration and networking is a strategic organisational response to the increasing complexity (hence cost) of R&D process and it is a prevalent trend. In the future we will see a further specialisation and division of R&D among many different agents and further collaboration, heading towards open innovation. Companies will further purchase more R&D and these demands become a business opportunity for those who provide services, amongst others for private and public research organisation and smaller firms.

The increasing complexity of research is a key driver of the cost of research. One strategy to mitigate the effects of this driver is to pursue collaborative research strategies. FP projects can support this strategy. However, concerns were expressed about FP7 programmes as being too bureaucratic and returns too uncertain as a result of the pre-competitive and long-range nature of the projects. Particularly large scale projects were considered as difficult to manage (transaction costs) to make sure each partner delivers and thus the whole consortium benefits. Thus, there is the risk that the costs and benefits of the FP participation becomes unbalanced. By the same token, high costs for PRO's regarding applications and reporting for public funding should be addressed by policy makers. By the same token, high costs for PRO's regarding applications and reporting for public funding should be addressed by policy makers. However, R&D programmes which are designed to promote science-industry collaboration generate more impact in terms of innovation than programmes without such policy design features[64].

The trend towards more collaboration and networking further heightens an existing tension in European R&D policy between fostering scientific excellence and supporting broader patterns of collaboration focused on achieving innovation outcomes (see also below). The trend towards more collaboration and networking implies that policy should further foster excellence and reduce barriers for knowledge diffusion and collaborative knowledge production.

[64] ZEW (2009): Analysing and Evaluating the Impact on Innovation of Publicly-Funded Research Programmes. Available at: ftp://ftp.zew.de/pub/zew-docs/gutachten/Implore-Final-04-2009.pdf

Given the fact that networking becomes more important on the global scale, European research policy should find new ways to integrate partners from outside the EU within funded research projects. In addition, outsourcing, which currently is often difficult or not allowed in by most EU research promotion funding schemes should be allowed more broadly.

4. Specific support programmes for infrastructure and equipment in PROs and specific industries

The case studies in PROs show that many respondents already have or expect to have problems to finance R&D. Every year research organisations must adjust the volume of R&D to match budget expectations. There are usually more project suggestions than budgets will fund; in a recession clients and sponsors are likely to impose budget cuts and reduce the volume further; this may stimulate a marketing campaign to attract new clients. Continuing public funding, however, is seen as a fundamental requirement to nurture the internal capacities within PROs that are needed to attract business from private sector clients in the first place and thus sustain a centre’s role of contributing to economic development.

Moreover, those organisations providing large infrastructure argued for a further and better coordination with a view to capital investments which requires merging national efforts in order to increase the performance of fewer installations by facilitating more diverse usage. Such strategies are under discussion with regard to CSF policy proposals, e.g. as proposed by EARTO in spring 2011. The lack of national funds for the establishment and management of new infrastructures could reduce its use while a new frame for the management of European consortia of large infrastructures, – if a political convergence among the countries is found –, could represent a positive solution to these financial impasses. The design of European Research programmes might have to reconsider rules regarding the share of grants or subsidies which can be spend on capital and infrastructure.

In general, information about cost indicators used within firms can lead to a deeper understanding of cost trends and factors, and thence to policy guidance. Using company and industry level indicators, policy advisors and makers might be able to check if the industry assertions are correct (i.e. that their R&D costs are indeed rising as claimed) and whether extra support might be legitimised.

In general terms, creating favourable market conditions for the private financing of R&D including venture capital and developing the financial instruments to promote larger private R&D investments is needed considering the challenges to fund R&D in general and capital investments more specifically.

Of course the ERA is a very significant way of addressing this. The concentration and sharing of facilities, provided that this does not restrict access or associated learning benefits, is a strategy that is consistent with R&D networking and collaboration (open innovation). However in considering the value of R&D, accumulated expertise and regionally dispersed expertise is important. Thus the strategic implications of concentrating expertise into a small number of locations should be evaluated in specific technology and application contexts. The purpose of investing in R&D may be to stimulate other entrepreneurial activities. Eliminating R&D expenditure is probably not an objective – ensuring that it is focused on the correct objectives is much more important. Exploiting R&D effectively is at the core of a knowledge intensive economy.

5. Use regulation to drive change in order to create opportunities

Regulation is one instrument of policy to govern the innovation and research system. Regulators themselves may use regulation to drive change in order to create opportunities for companies able to seize them. Regulatory pressures translate into a competitive advantage for businesses that do invest in adapting their products to regulatory requirements or indeed chose to take the lead in creating new regulations, standards and platforms.

The design of regulatory instruments is also related to the well-known Porter Hypothesis[65]. Ambec et al. (2011), for instance, argue that market-based and flexible instruments such as emissions taxes or tradable allowances, or performance standards, are more favourable to innovation than technological standards, because they leave more freedom to firms on the technological solution to minimize compliance costs.[66]

Our study suggests that regulation was seen as having the potential to strengthen R&D choices and the returns on investment as well. A key requirement to reap the benefits from regulation in terms of improved returns on investment for regulation-related research consists in using regulation to stimulate research that is directed towards societal challenges while harmonising regulation across Europe.

This will be particularly relevant, if and when the European Commission succeeds in aligning regulatory requirements in different European countries. However, this also has the potential to create tensions in an international trade setting, if the free movement of goods and services becomes increasingly restricted as a result of this. Positive effects of green regulations in promoting market development were evidenced in some of the cases. Climate change as one important grand challenge can be mentioned which offers opportunities for those companies who are able to translate create new markets for greener products and technological solutions.

Good policy examples at EU level are the Lead Market Initiatives, and the proposed Innovative Partnerships. Addressing issues like health, ageing or climate change can indeed offers opportunities for competitive advantages[67]. As such, regulation refers to one of the ways to integrate innovation policy and industrial policy[68].

6. Harmonisation of fiscal incentives for R&D within Europe

Gaining access to public R&D funds is not an important motivation in setting up international R&D centres, but may influence location decisions within a targeted country. Tax credits assume particular importance in a situation of restructuring or consolidation of companies' activities. In this instance, tax credits might directly influence the retention of an R&D centre. More generally, the significant effect of tax credits will be to nurture the science and innovation culture and hence the attractiveness of the region/country. The harmonisation of

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[65] Originally, Porter and van der Linde (1995, 110) argued that: *"If environmental standards are to foster the innovation offsets that arise from new technologies and approaches to production, they should adhere to three principles. First, they must create the maximum opportunity for innovation, leaving the approach to innovation to industry and not the standard-setting agency. Second, regulations should foster continuous improvement, rather than locking in any particular technology. Third, the regulatory process should leave as little room as possible for uncertainty at every stage."*

[66] Lankoski (2010, 6) reviews the empirical evidence to date and concludes that regulatory policies should aim to achieve win-win solutions. They are in favour of policies that provide incentives to innovation and focus on end results rather than means.

[67] EC (2010) An Integrated Industrial Policy for the Globalisation Era: Putting competitiveness and sustainability at centre stage, SEC(2010) 1276. See: http://ec.europa.eu/enterprise/policies/industrial-competitiveness/industrial-policy/files/communication_on_industrial_policy_en.pdf

[68] Braun, A., Grimm, V., Korte, S. Rijkers-Defrasne, and Wintjes, R. (2011): Innovation and Industrial Policy, ETEPS Study for European Parliament's Directorate A – Economic and Scientific Policy Department. European Parliament, Brussels.

fiscal incentives for R&D in different EU Member States and discouraging distortions of the competitive landscape within Europe is a further important policy goal.[69]

Given the expected further increase in importance of purchasing R&D services is also important to create a 'single-market' for R&D services in the European Research Area (ERA) and Innovation Union.

7. Address the fragmentation in EU public research: towards a new balance between scale and scope

It is not only companies and PROs that are searching constantly for a new balance between economies of scale and scope and between centralised and decentralised governance solutions. National and EU policy makers discuss and search for new appropriate balances in this respect (e.g. between excellence and cohesion[70]). European integration has its costs and benefits, but maintaining EU leadership in key RTD areas calls for more focus and concentration, and the creation of European Research Centres. With many national research institutes and national R&D programmes in every EU Member State, and limited differentiation among universities, more integration and collaboration allow for specialisation strategies. Initiatives such as setting up the European Research Council (ERC) and the European Institute of Technology (EIT), but also Joint Programming, Lead Market Initiatives, Technology Platforms and Innovation Partnerships are helpful in reducing this fragmentation. In an integrated Innovation Union more cooperation between national policy makers, and openness to participants from other Member States in National and regional R&D programmes, are important in developing decentralised networks of Smart Specialisation Strategies at regional level.

[69] Following the introduction of the R&D tax credit in France, Rhodia, for instance, reported that this measure had an influence on their R&D location decisions and enabled the company to retain R&D capabilities that would have otherwise been moved to lower cost locations, such as China. The Philips case illustrates how public policy was used to retain jobs during the 2009-2010 economic downturn by enabling R&D employees to temporarily locate in the local public research organisation or university. Boehringer Ingelheim's IMP's access to city funding programmes of Vienna enabled the company centre to lower its infrastructure and database costs.

[70] Soete, L. (2009), Summary of conclusions of the Expert Group on "The Role of Community Research Policy in the Knowledge-Based Economy", http://ec.europa.eu/research/conferences/2009/era2009/speakers/papers/paper_luc_soete.pdf

9 Policy-oriented Summary

In this chapter we summarise the main findings of our study from the perspective of research policy.

The findings are based primarily on the survey and case studies of 200 large R&D intensive companies and public research organisations (PROs) in Europe and a few selected firms from the US and China. In addition, we organised two workshops where experts discussed strategies and future scenarios to cope with increasing research costs.

We highlight specific results and discuss them in the context of European Commission policy initiatives, current policy debates and strategic goals at the European level such as Europe 2020. In setting out our findings we have considered the implications of specific changes in the dynamics of research costs for existing strands of European R&D policy, discussing more fundamental shifts and what possible European Commission responses might be relevant.

Empirical evidence for rising research costs: disruptive change, steady growth or slow down?

In the empirical study we examined the development of important cost elements, which are labour cost, capital costs (machinery, infrastructure, ICT), financing costs, costs of purchasing R&D (48%), cost of obtaining patents and 'other costs'. For these categories the accounting systems of companies usually provide reliable information. The study confirms that **research costs have grown in the past five years, on average by 47% across all industries**. **Wage costs** account for 50% of all of R&D costs in companies and 62% of the costs in PROs. Despite the high proportional representation in component cost and despite wage increases across many organisations, wage costs are not regarded as the most significant contributor to increases in R&D cost. Sixty percent of the companies surveyed reported that, in the last five years, **R&D cost increases were primarily due to increases in capital costs** (investments in infrastructure, machines, etc.) while wage costs, costs for material and supplies, and 'other costs' have grown by about 40%. Similarly, 35% of PROs reported that the largest component of R&D cost growth over the last five years has been capital costs. Compared to firms, PROs spend less for capital costs and for purchasing R&D. Companies expect that the cost of purchasing R&D (48%) and the cost of finance (41%) will grow in the next five years.

While **finance costs** (linked to a risky activity such as R&D) have not grown significantly in the last five years (5%), it is expected that they will grow considerably (41%) in the coming five years, mainly due to a volume effect. This suggests that there is an expectation that external funding will be more important and associated with that, the need to ensure better finance conditions (guarantee funds, etc.) and a strengthening of links with venture capital funds. This will only be possible if new businesses are developed which embed an understanding of the returns on capital invested in R&D activities. **Creating favourable market conditions for the private financing of R&D** including venture capital and developing the financial instruments to promote greater private R&D investments, are already an important aim of the European research strategy.[71]

Our study confirms that **costs for obtaining patents** are quite low compared to other cost categories and have grown less compared to other cost elements. While total R&D costs have grown by 47% in the last five years, the cost of obtaining patents, which makes up only

[71] ERAB, for instance, proposes the establishment of a European Venture Capital Fund. EU 2020 talks about "improve access to capital".

about 2% of all R&D costs, have grown by 25% in the same period. However, 37% of respondents expect that patent acquisition costs will grow more strongly in the next five years (37%) mainly due to a volume effect. Nevertheless, some firms argued that they now adopt a more selective approach to managing patent portfolios because of rising patenting costs. So while the importance of patenting costs for R&D decisions may be overrated in general terms, European Commission activities to harmonise the **IPR system** across Europe (e.g. create the single EU Patent, Unified Patent Litigation System) remain an important initiative in view of companies' expectations regarding rising patenting costs.

There are also **industry specific factors** which explain some of the trends observed. For example, total R&D costs have grown particularly strongly in the pharmaceutical sector and `other sectors' (e.g. Machinery, Electricity, Consumer goods). In both sector groupings capital costs and the cost of finance have grown more than the average growth rates that respondents ascribed to the average cost category. Costs of obtaining patents especially in the pharmaceutical sector have also grown. The automotive sector reports extremely strong growth (97%) in the cost of materials and supplies which reflects investment needs in relation to testing, using new materials, etc., for instance, in the development of alternative powertrain technologies. In the future, the ICT sector and pharmaceutical sector expect a strong growth of purchased R&D services and costs for patenting, while pharmaceutical companies also expect the cost of finance to rise further. In this respect, policies addressing R&D investment should also take into account specifics of sectoral differences.

The survey asked companies to assess whether research costs have primarily grown due to **price** (e.g. increases in the component costs of R&D, such as wage cost per researcher) **or volume** (e.g. increases in overall business expenditure due to an increase in the number of researchers or projects). There are various healthy reasons for volume changes including an expansion in the range and scope of the business and its R&D requirements, or scientific and technological opportunity. Taking into account this distinction reveals that total research costs have grown mainly due to a volume effect. The same holds for capital costs (e.g. machinery), material and supplies, and purchased R&D services. (It should also be noted that these costs can encompass hidden or embodied R&D in purchased goods and equipment – evidence that suppliers have performed useful R&D – and that purchasing or outsourcing R&D is a redistribution of costs rather than a reduction or increase per se). In contrast, the costs of financing and of obtaining patents have grown in the past mainly due to an increase in prices.

Expectations regarding **future developments of the cost of research for PROs** are markedly different: PROs expect that the cost of all research inputs will in the future grow mainly due to an increase in prices. They are rather sceptical as to their ability to expand activities (which would result in volume effects). This would suggest that careful policy attention is required with regard to understanding and helping to shape the balance of activities between different R&D players that is required to ensure optimum outcomes for European societies.

In total, the increase in research costs is expected to amount to about 30% in the next five years which indicates a **slowing down of the dynamic development over the past five years**. Companies also expect the growth in the number of R&D personnel to slow down over the next five years.

Taken as a whole, **research costs are expected to grow much more slowly over the next five years** than they have done over the last five years, which may reflect a number of reasons: On the one hand, companies may be expecting fewer new market opportunities in the future. On the other hand, companies expect that current economic and financial crises will have an impact on the costs of their activities. Companies' expectations regarding rising costs of finance to support their research activities may well be connected to changes in financial markets and the credit crisis. Companies may therefore revert to alternative sources of finance such as venture capital to fund their research. Although managers' estimations of future developments always have to be regarded with care, these findings could suggest that further steady growth is not possible as business confidence or productivity gains are not expected to increase as they have done in the past.

One immediate policy conclusion here relates to the long-standing European Commission commitment to promote an increase in the proportionate spend of EU and member state R&D to reach a target of 3% of GDP.[72] While our survey suggests that companies expect to spend more on R&D in the future, **the growth rate is levelling out and reaching the 3% target will remain challenging and it seems unlikely that this level will be reached soon.**

Globalisation of research and the role of research costs

Beyond policies targeting the dynamics of R&D spending in Europe, it is important to understand the implications of changes in R&D costs in terms of location decisions of European and overseas companies. Internationalisation of research is a major trend in the economy. Our study makes a contribution to understanding to what extent and how this trend is motivated and shaped by changes in the relative costs of research.

By and large, our results show that companies are likely to spend more on R&D outside the EU-15 countries, particularly in other EU 27 countries, US, Canada, China and India. We can confirm that European companies are increasingly turning to China and India as new locations for doing R&D. The survey clearly shows R&D expenditure by EU firms in these countries can be expected to increase considerably in the next five years (by more than 100%). What needs to be kept in mind, however, is that this is from a comparatively low base so that the relative share of investment in these countries will remain limited to only about 1-3%. However, taking into account that companies will spend more on R&D in absolute terms, more R&D activities will be undertaken in Europe as well. As a result, the growth rate of R&D investment is likely to be lower in the EU-15 than in the other countries, but nevertheless positive.

Our results indicate that companies **do not regard 'going abroad' as an important strategy to reduce R&D costs**. The survey found that expanding R&D activity to low-cost countries such as China or India was considered to be the least likely strategic option to contain research costs. In contrast to popular perceptions, the results indicate that increases in R&D expenditures of EU firms in China and India **are not due to cost advantages of these countries** in R&D. In line with the literature, we found that R&D investments in these countries are mainly motivated by market expansion and the adaptation of existing products and technologies to local consumer demand, regulation and environmental conditions, particularly in India and China. Moreover, some companies referred to R&D investments in China and India as a way to overcome a lack of qualified researchers and as a source for qualified researchers in scientific fields that are "out of fashion" in the West (like organic chemistry and other disciplines).

Thus, overseas R&D activities are complementary to rather than substituting for R&D activities in Europe. It is also worth noting that EU firms have also increased their R&D

[72] Within the race between countries to increase R&D expenditures to the highest level of GDP we should not forgot that this is input target only. R&D expenditures (costs) say very little about how efficiently those costs will be made.

expenditures in locations such as the US and Switzerland, which are by no means low-cost locations.

We also found that expanding R&D activities in **New Member States** is becoming more important, although this is a rather slow development. This finding may also be interpreted as a positive sign for the development of a **European Research Area**. Focusing on the development of a European Research Area should however be complemented with more openness to Non-EU researchers and locations, by promoting linkages with non-EU nodes in global(ising) R&D networks.

In the survey we further examined whether the cost structure varies between different R&D locations of the (multinational) firms in the survey. When asking the companies about the composition of their research costs we asked them to distinguish between the 'world main region' and the so called 'most dynamic region' (defined as the world region with the highest expected economic growth or the best opportunities for the company). Surprisingly, we found that the **'main world region' and 'most dynamic region' are not very different** regarding the share of wages as a percentage of total R&D costs. The market for highly skilled international researchers has become a global market with globally comparable wages, a result which was also confirmed by the case studies. However, purchased R&D is much less common in 'dynamic regions' than in 'main location' which suggests that in emerging and catch-up countries R&D services are still likely to be less developed.

There is an expectation that cost levels between emerging economies and the EU-15 will begin to stabilise over the coming years. Several case study interviewees in Europe and in China indicated that, in their view, China's competitive edge in high-tech manufacturing due to low labour costs is already diminishing. In addition, a Chinese manufacturer also sees an increase in the cost of materials, purchased services and capital costs further eroding the cost advantage of Chinese research and manufacturing locations. Levels of inflation and exchange rate fluctuations also have an important influence on the cost differentials between different locations.

The stronger orientation to outsourcing R&D and the importance of R&D strategy alignment with the core business may further reduce the off-shoring trend driven by a market exploiting behaviour. The process is evidence of the importance of **'home-based augmenting' strategies** pursued by multinational companies. All in all, strategic factors related to R&D and innovation capabilities are more likely to affect location decisions in comparison to cost factors.

One key issue that emerges from our findings is the need for policy makers to help firms to **strengthen ways of appropriating the returns from research spending from overseas**, or, in other words, to maximize the domestic (EU) benefits from foreign R&D. From a policy perspective, it will be important to take account of such positive effects on domestic productivity from R&D investment abroad. In line with this and the above mentioned 'home-base augmenting' strategy, there may even be a policy role in supporting domestic companies in identifying key locations and centres of excellence in emerging economies to maximise associated productivity gains. Less restrictions in EU and National R&D programmes to involve Non-EU researchers could promote the EU as 'host' region for Non-EU companies.

The presence of knowledge complementary to that available at home may require a successful **'reverse technology transfer'**. Crucial to reverse technology transfer is ensuring that the necessary absorptive capacity is in place to enable that this transferral is effective. An important part of this **absorptive capacity** relates to the human resources necessary to underpin and deliver the R&D effort and create the link to competitive economic production.

Beyond supporting European companies in maximising the benefits from establishing a presence in emerging research locations and centres of excellence, it will be equally important to enrich the European research scene with academic participation from emerging economies.

To help achieve this, strengthening collaboration with and easing **the mobility of and access to researchers and students from abroad** will be an important lever in integrating the cultural and market sensitivity into European research teams. By the same token, however, indigenous research talent needs to be nurtured by further promoting R&D careers at home. Enhancing the systems to endorse qualifications obtained elsewhere is an important requirement for both of these dimensions, within Europe and between Europe and other world regions.

Gaining access to public R&D funds is not considered a motivation to set up overseas R&D centres, but may influence precise locations within a targeted country. **Tax credits** assume particular importance to companies that are undergoing restructuring or consolidation. In this instance, tax credits might directly influence the retention of an R&D centre. More generally, the significant effect of tax credits will be to nurture the science and innovation culture and hence attractiveness of the region/country. The harmonising of fiscal incentives for R&D in different EU Member States and discouraging of distortions of the competitive landscape within Europe is hence a further important policy goal supported by our study findings.

Companies' response to rising research cost: defensive or proactive?

Our research results suggest that cost differentials between different locations or labour costs in Europe do not translate into large movements of R&D activity to low-cost locations. Nevertheless, companies need to develop strategies to respond to an increase in the costs of doing research. The evidence from the survey and case studies suggests that these strategies tend to focus on increasing and securing an appropriate return on investment rather than purely containing costs.

The study reveals very clearly that firms consider **spending on research not in terms of cost, but rather as an investment**.[73] Decisions about research investments and budgets are based on expected outcomes, risks and the strategic development of internal and external competencies. In conjunction with our finding that the cost of finance is expected to increase and a trend towards greater reliance on investment strategies to secure access to complementary competencies is evident, a policy focus on creating favourable market conditions for the private financing of R&D appears all the more important.

Cost indicators[74] are used for strategic research management, but companies were rather cautious in their use of these, because of the difficulties associated with measuring research outputs.[75] This reinforces the message that in general cost is not an important factor in

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[73] See in this respect also findings from the R&D Scoreboard survey in 2008 (Cincera et al. 2010) which revealed that market pull is the most important driver for increasing R&D investments.

[74] Typical cost indicators used are: evolution of the total budget of R&D; Risk adjusted cost and the time for getting a new drug to market; total cost of R&D to generate a patent; total project cost for new product (start till end).

[75] At the moment, is it also discussed to use research output metrics for FP 8, as for instance proposed by ERAB. ERAB proposes for FP 8 to create a *"commonly accepted set of research output metrics based on research impact and innovation delivery"*.

managing and directing R&D. Instead, companies tend to rely on a process of intelligence-led focusing of R&D that was seen particularly by case study interviewees as having a much greater effect on the value and impact of R&D on the business than cost reduction within the R&D department.

By the same token, reducing the risks associated with R&D investment and reducing the cost of failure by deciding more wisely 'what to do,' was seen as more important than simply reducing the cost of 'how to do it'. Creativity and uncertainty make it more difficult to measure R&D efficiency and more desirable to focus on R&D effectiveness and impact.

The survey among **companies and PROs revealed that improving worker productivity** was considered the most important strategy to contain research costs. This may be realised through a number of managerial activities: One way of ensuring that staff working in research facilities are used productively is to develop full service packages around the scientific use of facilities and thus use the facilities themselves and the staff delivering such services to their full potential. The notion of worker productivity thus relates more to activity levels rather than faster working.

Sharing scientific research facilities in response to increasing costs is one specific way of increasing the productivity of both R&D staff and the facilities themselves and thus managing the increase in the cost of facilities and equipment. This often involves public and private players.

Finally, environmental legislation was considered the most important cost driver and one that most urgently requires proactive strategies in response. Several case study interviewees perceived environmental legislation as creating an impetus to identify and exploit new **opportunities**[76] rather than interpreting it as a reason to lower environmental standards in Europe. In that sense, regulation incentivises investment in new 'breakthrough technologies' in order to respond to the new societal concerns that motivated regulation in the first place. The Strategic Research Agenda for the European Aeronautics and Air Transport, for instance, has shifted research investment towards a focus on finding new breakthrough technologies in order to comply with regulation. Regulatory pressures translate into a competitive advantage for businesses that do invest in adapting their products to regulatory requirements or indeed chose to take the lead in creating new regulations, standards and platforms.

In that sense, research can and should contribute to addressing societal challenges (Grand Challenges) such as climate change moderated by intelligent regulations which could contribute to the direction of technological change.[77]

Networking and collaboration as important response to rising research costs

Collaboration and networking is key in dealing with rising research costs. The **increasing complexity of the research process** and associated technology and innovation requirements are considered to be the most important driver for an increase in research costs. This creates a strategic need for collaboration. For instance, there is an increasing need for multidisciplinary projects and the fusion of technologies and research strategies (e.g.

[76] Cincera et al. (2010) support these findings when the report that product market and other legal framework are important for about 50% of the companies as driver for increasing R&D investments, though, this is more important for companies in low-tech sectors than in high-tech sectors.

[77] Compare in this respect also the findings from Porter and Linde (1995).

bioinformatics and electro-mechanical). It also requires new interfaces between R&D and other functions in an organisation such as marketing, sales, design, strategy, etc. and similarly with other organisations in the value chain. Networking is not just about managing costs but a distinct way to conduct research in an efficient and productive manner.

Collaboration, however, brings with it new types of cost, such as the costs of managing relationships and partners, network costs, project management costs, etc. Moreover, off-shoring and outsourcing have a lot of attractive features in a world of research collaboration but come with a price as it may become more difficult to be ‘leading edge’. However, this all depends on the research and innovation strategies companies are pursuing.

Different sectors will move at different speeds and directions and these could be illustrated or examined but, notwithstanding this potential for variation, the main trend is toward research becoming a much more collaborative effort with more centralised or ‘closely held’ research strategies and activities less likely to be the ‘norm’.

With respect to managerial strategies to cope with growing research costs, the company survey found that collaborative networks were regarded as highly important to address the challenge of increasing research costs. **Collaboration is the second most important strategy (after improving worker productivity) for companies and PROs.** The increasing trend toward spending more for purchased R&D is a further finding which is in line with the development towards ‘open innovation’. Networking, collaboration and ‘Open Innovation’ also seems the most important strategy for National R&D policy makers: promoting cooperation between science and industry, and between the National R&D programmes and institutes of the Member States, but also increasing the Openness of the European Research Area to the rest of the world.

Networking and collaboration manifest themselves in various forms which can all be included under the umbrella term **‘open innovation’**[78] with changes in the role and organisation of R&D being a major aspect. A plethora of collaboration mechanisms are used by different R&D actors including strategic partnerships with (several) universities, venture capital investments, the acquisition of technology businesses, and focusing R&D on innovation objectives instead of scientific objectives. Taken together these developments amount to a fundamental change in the R&D landscape and the location of different activities in R&D supply chains.

Although major corporations have enthusiastically embraced open innovation philosophies, there are some indications raised from the case study interviewees that **collaboration might also be associated with higher (transaction) costs** that need to be carefully managed. Concerns about losing expertise in areas of core competences reinforce this scepticism. There may be additional administration costs and inefficiencies associated with collaboration.

Support for collaborative research has, of course, been a focus of European research policy for many years. **FP projects** are designed to facilitate and enable the benefits to be derived from collaboration and networks. Indeed, our survey found that an average of 1-3% of companies’ total R&D budget is dedicated to participation in FP projects. For some companies, however, FP finance can provide up to 40% of their total research budget (though, only the ‘R’ component of R&D). For the latter organisations, administrative burdens and transaction costs do cause some concern.

[78] The term ‘open R&D’ tends not to be used.

For many companies, participation in FP projects is seen as providing strategic advantages over and above the immediate research outputs that can be achieved. They are seen as offering opportunities to do projects with new partners and to engage with 'unlikely' partners in new fields. FP projects also provide incentives to enter entirely new research fields in the pre-competitive arena.

Minimising the perceived financial risk and the barriers to entry or perceived affordability are subtly different motivations from a cost-reduction motivation. Consequently, the FP schemes may in fact cause increased expenditure, inducing activity that would otherwise not be undertaken. When the outcomes of research are not closely specified, the justification to engage in that research is more difficult. What is needed therefore is either creative strategic justification or tangential learning benefits. Projects involving standards were considered particularly as useful, not only by the studied European firms but also by one of the interviewed US firms (which has a European subsidiary).

Similarly, the survey asked respondents about the importance of **applying for subsidies and tax incentives to contain research costs**. These funding opportunities were considered on average to be of medium importance. In many industries and businesses, the use of public subsidies for research is often not linked to the direct cost of doing research, but motivated by the returns in terms of networking, vertical and horizontal consortia building, and knowledge and reputation that can be realised through collaborative projects (e.g. FPs). The direct financial benefits tend to be of a small order in proportion to companies' own funding for research. In other industries, however, finance through the FPs plays an important role for research funding (see above).

The trend towards more collaboration and networking further heightens an existing tension in European R&D policy between fostering scientific excellence and supporting broader patterns of collaboration focused on achieving innovation outcomes. This implies the need for policy to reconcile that tension and **further foster diversity of participation rather than purely excellence**.[79] The trend towards more collaboration and networking implies that policy **should further foster excellence and reduce barriers for knowledge diffusion and collaborative knowledge production**. Such barriers encompass technological, institutional and geographical barriers.[80] In the past, FP was successful in the inclusion of new European countries.[81] It will be necessary to think carefully how to design R&D support measures at the European level to optimise their outcomes in terms of reinforcing the circulation of knowledge and convergence between member states and regions. It is hence important to find a balance between a European policy of fostering excellence (picking the winners) and sustaining variety and cohesion. Even if **antitrust policy** has rarely been justified within the research field, more attention in respect to collaboration, joint ventures and networks is needed.

Policy should avoid promoting the concentration of resources on a few networks. It should also consider any associated unintended negative results in terms of researcher mobility particularly for those regions or countries which experience a brain drain of good researchers. Although in current policy, mobility is fostered and celebrated, this may result in a net loss for countries with good systems of education but relatively low wage levels and standards of

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79 The reinforcement of co-operations between business, universities and research and the enhancement of cross-border co-operation as suggested by the Innovation Union Flagship Initiative (2010, 13) is thus supported by our study.

80 More recent studies have shown that the Framework Programmes have significantly contributed to the more integration in the European Research Area. The study of Scherngell and Lata (2011), for instance, shows that barriers mentioned above have been reduced within FP networks over the time period 1999-2006.

81 See for instance Heller-Schuh et al. (2011).

living, such as Eastern European countries. Therefore it is important to also create incentives for researchers to return or for attracting researchers from abroad in order to balance the effects of outward mobility of researchers. Above all this requires a pro active policy for the real application of the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers (2005)[82], in order to establish a level playing field in terms of conditions (salaries, career, etc.).

Promoting strong, focused, geographical concentrations of research excellence in the EU (e.g. by supporting Smart Specialisation strategies[83] at regional level) is an important policy response to the above conclusions.[84] First it is instrumental in regarding trends in costs and regarding the position of the EU as nodes in open R&D networks at a global level.

A reshaping of the organisational structure of R&D activities can be seen to emerge from the study findings. More open and flexible models of deploying corporate R&D resources will be required in the future. The providers of R&D services will not be limited to universities, PROs and other RTIs and consultants, but will extend to a wide range of companies, large and small including R&D intensive companies. While this creates new business opportunities in developing and delivering specialised R&D services, the strategic focus of R&D efforts in larger companies might get diluted when hitherto internal and functionally organised R&D activities get diffused in (amorphous) R&D services industries.

So while this development creates **business opportunities for those who provide new R&D services, it will be important to ensure strategic focus from a societal perspective.** As stated above, the survey results suggest that the share of purchased R&D services is higher in the European home-base than in the more dynamic regions. The quality of such buyer-supplier networks of R&D (including low networking costs) in Europe will therefore become important in preventing a further reduction in the share of R&D activities taking place in Europe.

A new research paradigm based on collaboration?

Considering the overall patterns and trends revealed by the survey and case study evidence, the study provides evidence of a changing paradigm of doing research which is characterised by multiple and diverse collaborative arrangements, new funding schemes and business models.

Collaboration may be seen as merging with networking as a trend and the evolution of more efficient knowledge eco-systems, accompanied by a growth of R&D based services and the creation of new business models for R&D and new types of businesses. The new paradigm includes a tendency towards a division of labour and sharing of risks for increasing R&D investments, rather than merely off-shoring for market reasons; towards rich and user-led research demand, and towards accessing a larger pool of patents. A new division of labour between companies, PROs, universities and service providers on a global scale is thus the result of increasing complexity. This new research paradigm may also have an effect on the

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82 These two documents are key elements in the EU's policy to make research an attractive career, which is a vital feature of its strategy to stimulate economic and employment growth.

83 Foray, D. and van Ark, B. (2007): Smart specialisation in a truly integrated research area is the key to attracting more R&D to Europe, Expert Group Knowledge for Growth, Policy Brief No. 1, http://ec.europa.eu/invest-in-research/pdf/download_en/policy_brief1.pdf

84 A Smart Specialization Platform was announced in the communication "Regional Policy contributing to smart growth in Europe 2020" with the purpose of assisting regions and Member States to develop, implement and review regional smart specialisation strategies.

ability to transfer research into innovations, a capability which is considered as a weakness within Europe (European paradox). In the future, new strategies by even more flexible ways as in the past have to be realised (requiring for instance governance of global networks, absorption ability, diverse business models, organisational ambidexterity) in order to transfer knowledge between the different actors involved in the innovation process. Further studies would be needed in order to examine in more depth to what extent European companies are equipped with such capabilities compared to their major competitors from the US or East Asia.

The study delivered evidence that research costs will further increase in the future, however, companies will at the same time adopt new strategies to expand the outputs and hence keep productivity high. **There are no signs that companies are unable to cope with the speed and changing nature of R&D, or that we are generally suffering from diminishing opportunities for new scientific and technological discoveries.** European companies are able to respond to the growth of research costs. This means that the intelligent focusing of research activities and R&D management methods more generally can have a much greater effect on the value and impact of R&D on the business than cost reduction within the R&D department. In this context, **the diffusion and awareness of management models based on technological strategic orientation (roadmap and foresight)** will become more important, being able to design competitive research strategies and business models taking into account the changing technological, market and regulatory environment.

In this context, we identified some typical strategies that companies may pursue in the future to deal with their many different challenges. For example, the extent and possibilities to collaborate and the degree to which an industry is 'science-driven' rather than 'market driven' are important factors which will greatly influence locational, human resource, and infrastructure investment strategies.

During the expert group discussions **different human resource strategies** were identified that are either about recruiting research 'stars' or alternatively are concerned with investing in the development of research teams and more flexible and broadly based research skills. The experts noted, for instance, that in some sectors they will continue to put great emphasis on science as the basis for, and outcome of, research. In other sectors, the focus is to a much greater extent on the 'application' of the science hence requiring greater 'market' intelligence and sensitivity. The costs of attracting the top, most skilled individuals to work on research are high. Attracting stars involves high salaries, attractive locations and similarly competent teams.

At the same time, companies may see particular **opportunities to co-locate with other research performers or to re-locate close to reserves of science and technology expertise**, thus gaining research performers opportunities for positive spillovers derived from R&D investments made by others. Buying into these spillovers is an important means of managing the costs of research. At the same time, capturing spillovers does incur costs of a different nature, but offers more broadly based human resources or, in the case, of relocations to emerging market locations, additional cultural and market intelligence.

A typical strategy companies may choose in the future can be labelled as **'portfolio builder'**. In response to the increasing complexity of technologies and the speed with which technologies advance and change, these companies are driven to find new models for the conduct of research that maximise the chance of research success while allowing the costs of research (and failure) to be more predictable and manageable. Portfolio builders are concerned with acquiring research results that will provide a pipeline for the exploitation of IP at many and unpredictable downstream stages and in different spheres of activity. Portfolio builders place their focus on science-driven research, the results of which allow them to be responsive to new science and technology breakthroughs and platforms. To achieve this end, they must carry out research that frequently requires significant investment costs in research programmes, skills and infrastructures.

Another, rather contrary strategy can be categorised as **‘predator strategy’**. Predators actively seek out market, knowledge and network spillovers from outside of their own organisation, scanning, often in a systematic way, the research environment and exploiting spillovers while minimising their own internal research costs. Predators can be found where the ability to exploit research capacity and results are the key factors in creating and maintaining a competitive position rather than the ability to generate research results. By adopting this approach, predators implicitly accept the opportunity costs that are attached because they are not doing the research themselves. They accept the risk of potentially being left behind in their research domain by buying in and buying up research talents and results. To further mitigate against their risks and opportunity costs of **‘not doing research’**, predators actively choose to co-locate with research performers particularly where these are also located close to important end-markets and research users.

Thus, in some circumstances not doing research may be a valid strategy and will minimise costs in the short term. Being more opportunistic and scanning more effectively offers the possibility of being able to sit back and acquire the necessary research results but, as with outsourcing, there are risks and costs attached to not being active research performers.

PROs increasingly difficult role as research performers

The emergence of a new research paradigm raises some fundamental questions about the role of PROs in a new research landscape and their ability to develop suitable strategies and responses.

The empirical study of PROs showed a rather deflating picture about their possibilities to finance and manage research activities taking into account the changing research landscape, rising research costs, funding opportunities and their governance structures. The survey showed that PROs spend less for infrastructure, machines, equipment and ICT, i.e. capital costs (13%), and less for purchased R&D (7%) compared to companies. Interviews with PRO managers confirmed that research organisation increasingly **face problems in funding their infrastructure**. In addition, they have less possibilities, intentions or efficiency pressure to use more strongly external partners within the research process.

In line with this argument, the study revealed that the PROs did not recognise the drivers of research costs (e.g. availability of researchers, complexity of R&D process, cost of patenting, environmental regulation) as cost inhibitors (those factors which help to reduce cost). However, they consider public policy measures to support the mobility of researchers or measures to support research commercialization as factors that contribute to an increase in the costs of research[85]. These two policies may have some drawbacks and it is important to take into account that researchers’ mobility for some countries with worse conditions in terms of rewards and career options means “the loss” of good researchers. In general, attracting leading researchers is costly, and increasingly becomes a challenge due to a lack of

[85] Although it is unlikely that for instance the coordination costs are larger than the value of the subsidy received, costs such as for applications, reporting and coordination are seen as ‘cost-increasing factors’, especially for the next five years.

resources, in particular when national scientific labour market regulation doesn't allow a flexible management (reward) of human resources.

The commercialisation of R&D results is still more often associated purely with costs - even if it can have a signalling meaning - and it is especially so in the context of the decline in current core funds (government funding), since the internal technology transfer offices have no more resources for managing this activity. It may also indicate that PROs so far have not been very successful in their additional activities to commercialise their research results.[86]

Moreover, the increased competition among PROs and other R&D performing actors seems to drive the **cost involved in applying for grants and subsidies** higher and higher. This results in increased administrative costs. This is linked to the increasing importance of project funding as opposed to core funding that brings some drawbacks such as using time and capacities for responding to a number of calls for financial rather than scientific reasons. However, administrative costs needs to be minimised, provided that doing so does not impede R&D progress**. The high costs for PRO's in developing applications and reporting for public funding should be addressed by policy makers.**

Managerial strategies available to PROs to deal with rising research costs also seems to be more restricted in their possibilities (which is also due to their formal obligations, organisational aims, governance structures, etc.). In PROs, the expansion or relocation of R&D activity to other (low cost) countries has not been an important factor in managing PROs over the past five years. In any case the development and maintenance of R&D capability within a particular region can be part of its raison d'etre. In line with the evidence above regarding a low share of cost for purchasing R&D, PROs explicitly mentioned that they less often use outsourcing strategies. In general, besides improving worker productivity and the expansion of collaborations – which in companies are the major strategies to deal with rising research costs – eliminating less important R&D was considered to be important as well.

Understanding more clearly how R&D is evolving and how it can be organised effectively to recognise and exploit the evolution can lead not just to competition between PROs nurturing competitive advantage, but more significantly to a higher value-added status in global knowledge and technology markets. What is important in R&D performance is to be operating at the leading edge, to gain experience which enhances and advances capabilities at the leading edge and to have a reputation for doing this. This (rather than being cheaper than competitors) ensures invitations and opportunities to be involved in the most exciting projects. Being excluded from such projects will lead to a downward spiral.

Given that PROs have a public good mission and exist to serve important national functions (including maintaining excellence and competence) it is the extent to which they achieve objectives rather than marginal cost increases that should be the primary policy concern. This is a key area for public policy in the European Union. The nature of the public good mission of PROs will need to be defined much more sharply in order to allow the development of suitable policy responses that will create a clear position for PRO in the emerging new R&D landscape.

Policy support for capital investments in PROs is of particular importance here. Despite some recent initiatives (ESFRI, FP Capacity Research Infrastructures) on the European level,

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[86] A study of licensing activities of US universities shows that only about half of the universities how have set up technology transfer units or programs have reached the break even within the first four years, in about half of the cases the earnings from patents do not cover the cost to organise the technology transfer activities (Brandt et al. 2005).

more specific programmes are needed to cover the many different demands and types of infrastructure in PROs. This will need to be tied in with an understanding of how companies could and should benefit from public investment in research infrastructures. Market failures are currently translating into companies in some industries (nanotechnology, partly biotech) lacking the world class infrastructure that would be needed to secure their long term competitiveness.

Overarching conclusions

In general, information about cost indicators used within firms can lead to a deeper understanding of cost trends and factors, and thence to policy guidance. Using company and industry level indicators, policy advisors and makers might be able to verify if the industry assertions are correct (i.e. that their R&D costs are indeed rising as claimed) and whether extra support might be legitimised. In this context, policy makers should be interested to know if support (intellectual, facility or finance) is needed at certain times within the project cycle or under certain circumstances; trends derived only from total project costs might obscure this information. Peak costs and the costs of specific skills, expertise or technology might be useful indicators for policy intervention.

However, policy implications cannot and should not simply be identified in terms of how costs can be reduced. Rather, policy should take a more holistic perspective to understanding how cost developments and their impact on strategic choices will affect European productivity and competitiveness. So, how can policy influence the research process in companies and PROs, taking into account the challenges that are posed? Adopting a holistic view includes consideration of business strategies, R&D and innovation strategies, the roles of PROs in knowledge and technology 'eco-systems', and the attractiveness of R&D jobs and working environments. Policy implications should hence not be identified primarily to address or encourage cost-reduction. R&D is best regarded not just a cost to a business but as an investment.

For policy purposes R&D can be perceived as even more than this: It is also an intangible asset – to businesses and to regions. The expertise needed to perform R&D is an asset. More experience in R&D, combined with good strategic management, results in increasing asset value. In addition R&D activity is a growing knowledge intensive industry. It is precisely the kind of economic activity which we should nurture for employment creation purposes. Moreover the barriers to entry are significant and Europe already has built up a significant competitive advantage in this activity.

In strategic cases both R&D outputs and R&D expertise can be the basis for new or revitalised industries. In a global knowledge-intensive economy R&D capability is a valuable product or service that is traded. R&D (services) are a significant industry – especially for PROs. Thus the price at which R&D can be 'sold' (i.e. its value) is more important than its cost. Rising prices in the market indicate increasing asset value and higher potential margins – from an R&D supplier perspective.

One issue that emerges from the internationalisation of research and increasing collaboration is the need for policy makers to help strengthen ways of appropriating the returns from research spending while at the same time being alert to the fact that costs must also be allocated adequately to different research activities and stages.

European policy must hence consider how best to strengthen Europe's role as a global R&D supplier, especially at the frontiers of science and technology and in complex subjects and challenging problems. These might be the areas where costs are most obviously rising, but evidence of such cost trends in Europe can also be regarded as evidence that European organisations are competing in the most appropriate markets. It would be more worrying if R&D in Europe were being conducted mainly in low-cost subject areas.

Of course it is also important to ensure that healthy businesses and services are built on and around these leading areas of R&D. All industry sectors and public services could benefit. But the recommendation resulting from this strategic and exploratory look at R&D cost trends is to regard R&D as more than a source and inspiration for innovation. The latter focuses attention too narrowly on the cost of R&D. Focusing attention on R&D capability and expertise as an intangible asset recognises the value of R&D.

European Research policy can promote a better understanding of the VALUE of R&D and how this can be measured and communicated. This can be organised at various levels to different constituencies: investment banking and venture capital, industry, PROs, government agencies, MBA education, R&D scientists and technologists, etc.

10 Methodological Appendix

The COST project combined a survey approach with case studies to investigate the research questions. In this chapter the methods are described in more detail.

10.1 Survey construction, sample and non-response analysis

10.1.1 Preparation and conducting the survey

The empirical work started with the construction of the questionnaires which operationalised the research questions. After a series of revisions and alignments with the client the questionnaires were completed in October 2010. A questionnaire for companies and a questionnaire for the PROs was developed, both using a subset of the identical questions (e.g. drivers, management strategies) which should allow a comparison between PROs and companies. In general, the COST study team faced the challenge to master the trade-off between incorporating as many questions as possible to adopt all issues and questions of the tender whilst at the same time maximising the response rate.

A pilot run was done by personnel interviewing which resulted in slight changes to the questionnaires. In general the impression of the interviewees was that, although the questions were clear, answering all the questions was regarded as a time consuming affair. This comment applied especially to the quantitative cost data, because the questions required searching for or even calculating the requested information.

The questionnaires identify and confirm cost components and relevant developments and opinions from a practical perspective. The categorisation of this kind of questions was based on the literature study, and feedback from experts and the Commission. The final questionnaire covers five categories[87]. The first three are quantitative and the last two are qualitative in nature:

- Location of R&D;
- Cost composition of R&D;
- Cost developments over past five and next 5 years, including numbers of employed R&D personnel;
- Drivers of the cost of R&D;
- R&D management, strategies and R&D cost indicators.

The survey was web-based, with the additional possibility to answer by postal mail. Computer-aided web based interviews (CAWI's) were also available to support respondents

The address list used for the mass mail for companies was the one which the project team received from the project officer and is based on the address list from the R&D investment scoreboard survey organised by the IPTS (Tuebke 2009). The address list of the PROs was derived from the EUPRO database which is build up by the AIT (see below). No e-mail addresses and specific contact details are included in the address lists (R&D Scoreboard list, PRO list) and a search of possible detailed contacts and mail addresses for all 2.500 organisations was not possible with the given resources; the team therefore decided at first to contact the firms by postal mail. However, on the first page of the questionnaire there is a link given which allows respondents to fill out the questionnaire via web return. The experience

[87] See appendix A for the questionnaires as sent to companies and PROs. Note that the PRO questionnaire is slightly different from the companies questionnaire.

shows that some respondents returned the survey to MERIT by mail, but most respondents submitted their answers via the web.

With the final lists of addresses of companies and public research organisations, the questionnaire was ready for mailing to the CEOs (Companies) and Scientific Directors (PROs). The mailings began in week 43-44 (25 October - 5 November 2010). Questionnaires were sent out to 1.994 EU and non EU companies (Companies) and 543 public research organisations (PROs).

First responses were received on the 15th November 2010 from companies and on the 9th November 2010 from public research organisations. In December (20 December 2010) the numbers of responses were 38 from Companies (and 11 from PROs), end of January 50 Companies and 18 PROs had responded at the end of February these numbers increased to 82 Companies and 30 PROs and finally at the end of March (when the survey was closed) 103 Companies and 64 PROs had participated in the survey.

Table 26: Number of responses between December and March.

	20 Dec. 2010	30 Jan. 2011	28 Feb. 2011	30 Mar. 2011
Companies	38	50	82	103
PROs	11	18	30	64

The response rate was improved by the project team by several actions. These started by reminders by employed persons to the addressees to complete the survey they had received by the end of October. The follow-up procedure was as follows: if no response after four weeks, one reminder was given by a phone call followed by e-mail if possible. If there was still no reaction then at least three more emails were submitted. If no response was received, especially from the larger or more R&D intensive Companies, then additional phone calls were used. These served as a last attempt to minimize the non response. The organising principle of the survey can be described as a “flexible response”. After the mailing of the survey the team waited four weeks. After this period the team began with the follow-ups aimed at EU Companies and PROs. The purpose of the follow-ups was to gradually lower the initial non-response. The study team started to organise the follow-up in the beginning of December 2010.

The follow-up procedure required one or more telephone calls – and if necessary and possible – a maximum of three reminders using email. Thereby the main task was to identify the relevant person within the firm, send if necessary again the questionnaire, and assist the respondent to do the survey via the web (CAWI). In many cases the questionnaire was sent again by mail or fax to the identified contact person who had signalled a willingness to participate. But in some cases the questionnaires disappeared within internal co-ordination and administrative processes; for example a CEO might nominate the R&D director who in turn might nominate an R&D controller). The follow-up action was done by involving all partners of the project team – this made provision for native speakers to communicate with the Companies and PROs. The focus was on European Companies (represented in the Industrial R&D Scoreboard) and the more significant or larger PROs.

A number of other complementary actions and strategies were completed to support the survey response:1) refusal conversion was focused on EU companies only, since their potential interest in the survey is higher than of non-EU Companies and successful conversion more likely, 2) a "benchmark" was designed into the web survey as a motivational device to show how the respondent's organisation compared with others who had already responded. This was calculated 'instantly' – at the end of the questions – from the averages of previous respondents' answers. 3) An accompanying letter signed by the European Commission was provided to motivate Companies and PROs to participate. It explained the importance of the exercise.

One of the reasons for the low response is that the questionnaire contains more questions in which cardinal quantitative information (e.g. the exact, factual costs) is asked for, than we originally planned to ask. This implies more effort from the respondents (e.g. in terms of having to look up or calculate the actual numbers) than for the easier to answer qualitative questions, where respondents can simply tick boxes.

According to the tender specifications the study delivers a database. As agreed with the respondents (see the appendix of questionnaires regarding the survey privacy) the team delivered an anonymous firm-level database to the client, DG Research & Innovation. The individual answers of companies are not traceable, because information fields containing names and addresses have been deleted and the detailed information on the number of employees (which is publicly available) has been transformed into three size categories.

The cleaned database resulted after an analysis of plausibility and accuracy of the data (e.g. avoiding double entries and obvious 'outliers'). After the close of the survey (31 March 2011) the database was constructed and soon thereafter submitted to the client.

10.1.2 Non response analysis

The initial response rate in December 2010, 5-6 weeks after posting the questionnaires, was 1.2% for Companies and 1.3% for PROs. Due to this low response considerable efforts were done which resulted in the increase in response rates to 5.2% for companies and 12.8% for PROs. The improved response rates have lead to satisfactory and reasonable results, which are in line with experiences of other surveys of this kind. This response rate is comparable with results of more recently conducted surveys which ask for quantitative and competitive-sensitive information and are based on questionnaires with a similar length. The IPTS R&D investment survey (Tuebke 2009), for instance, achieved in the first exercise a response rate of 4%. The European Manufacturing Survey has since 2004 been coordinated by ISI Fraunhofer in five European countries and achieves on average a response rate of 7% (Dachs 2011).

In general, the response rate is determined by several factors:

i) The undeliverable rate of the mailed questionnaire (15%),

ii) The length of the survey: to incorporate all required questions we confronted our respondents with a very long questionnaire (8 pages). Normally a two page (max) questionnaire for business surveys will get a response rate between 3-15%, depending highly on the region in which it is conducted.[88]

iii) The kind of questions: it is well known that quantitative questions exhibit a lower response rate than qualitative questions.

iv) The appeal of the questions to the respondents: in this case the topic 'cost of research' as presented with policy objectives was not deemed to be a hot topic, and as a result it received mediocre attention.

[88] See e.g. http://econsultancy.com/uk/forums/best-practice/industry-stats-uk-on-line-survey-response-rates

v) The most important determinants of the response rate however is the effort given to refusal conversion.

During the process of refusal conversion potential respondents came up with reasons not to participate in this survey, one company (i.e. Schindler) even responded with a pre printed card with the following text[89]: *"Please take note that according to our Group policy the company does not participate anymore in surveys. Due to time constraints, it is impossible to handle the countless requests which are being submitted".*

Informal feedback from those involved in refusal conversion resulted in a list of the main reasons for not participating in the survey for companies and PROs. More or less in order of importance the list is as follows:

- Time and personnel shortage
- Participation in some selected other (national) statistical surveys
- Financial departments concentrate on annual report in this time of the year
- Survey is too detailed, hence too time consuming
- The numbers and trends are not available
- Too much time is necessary to answer in a decent quality and accuracy
- No will or allowance to release numbers in such a detail
- No interest
- Priority to national surveys (Switzerland)
- Not able to answer
- Institute of University
- No public research organisation
- No R&D
- No autonomous institute

Apart from these reasons several respondents visited the web sites of the survey, looked for a while and disappeared and never returned. The reasons for this behaviour cannot be explained, but it is very likely that there was no interest because the potential respondent regarded it as too time consuming or was not able to answer the questions.

About 50% of the website visitors (53% in the case of companies) submitted a response to the questionnaire (most of them by pausing and returning again).The other 50% did not submit the survey explicitly, but visited the web site, gave some answers (or not), stopped giving answers, and did not return. The ones that gave answers completed on average 51% of the questions; (this might be regarded as an indication that the questionnaire was twice the optimum size). But it also depends on the type of questions, as quantitative questions (especially about financial information and R&D information – which influences competitive advantage) will always remain more prone to low response rates than qualitative questions.

10.1.3 The company sample

The companies included in this survey are those that participated in the 2009 EU R&D Investment Scoreboard. The numbers of these firms are 995 non-European and 979 European companies.

The EU population of companies differ from the non-EU population with regard to the average amount of R&D spending as well as its spread (standard deviation) (see Table 27). EU companies spend on average (less than) half the amount of the NON-EU companies, while

[89] This text is also written in German and French.

the distribution of R&D around the average varies 50% (based on the coefficient of variation mentioned in Table 27) more in EU compared to NON-EU companies. Thus from a statistical point of view the selection of a large company (in terms of R&D expenditure) is less likely for an EU company than for a NON-EU company, the opposite is true for the companies with smaller R&D expenditures.

Figure 46: Cumulative distribution of share in R&D expenditure among EU and NON-EU R&D scoreboard companies (2008).

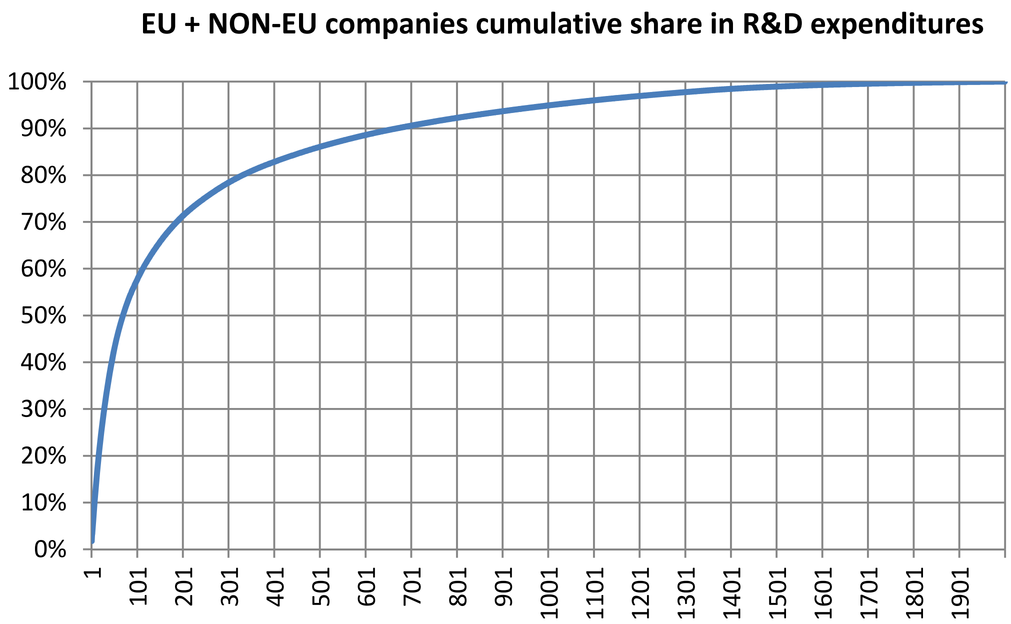

Table 27: Average (μ), standard deviation (σ) and coefficient of variation of R&D expenditure in EU and NON-EU scoreboard companies, 2008

	μ	σ	σ/μ
EU	130	496	3.80
NON-EU	300	746	2.48

The populations of EU and non-EU companies are also different in terms of the sectors of industry covered, as exhibited in Table 28. Responding companies give a good representation of the sectors in the economy of EU. Therefore, the non-response analysis shows that concerning sectors the response to the survey is representative. However, the number of responding non-EU companies was quite low and thus this group of companies is not well represented in our final sample.

Table 28: Share of selected sectors in EU and non-EU population of companies (2008) and the companies that have responded in this survey.

	EU companies	Non-EU companies	Responding Companies
ICT	31%	46%	26%
Pharma (incl. Chemical)	20%	18%	22%
Automotive	13%	7%	14%

Other	36%	29%	38%

10.1.4 The Public Research Organisation sample

PROs were selected from the EUPRO database. The EUPRO database contains comprehensive data on funded research projects of the European Framework Programs (FP1-FP7) featuring systematic information on project titles, project objectives and achievements as well as on the participating organisations including the full name, the full address, the respective NUTS-region and the type of the organisation. The database builds on raw data provided by CORDIS that are quite inconsistent (organisation names are spelled differently, fields are missing, etc.). Thus, the EUPRO database is a clean and consistent dataset from the raw data resulting in the EUPRO database.[90] The underlying assumption for using the EURPO database is that important PROs in each country at least once participated in a FP in the last 15 years.

All partners were engaged in identifying persons in the organisations that would be placed on the mailing list. The initial list contained 30,932 addresses of PRO that have participated in FPs 1-6 (EUPRO Database).

Table 29: Addresses and country in the PRO mailing list.

	Number of addresses in country	Useable responses
AT	13	6
BE	14	0
BG	6	0
CH	12	1
CZ	13	0
DE	69	12
DK	15	3
ES	54	12
EE	6	0
FI	16	5
FR	48	1
GR	16	0
HU	14	0
IT	65	4
LT	6	1
LV	6	0
LU	14	1
MT	5	0
NL	10	2
NO	20	5
PL	19	2
SK	7	0

90 At present, the EUPRO database represents the most comprehensive cleaned database on FP research projects and constitutes an extremely valuable resource for any kind of empirical analysis on R&D networks across Europe (see Scherngell and Barber 2009). The current version (March 2011) comprises information on more than 60.000 research projects and participating organizations.

RO	9	1
SL	13	2
UK	48	0
SE	26	6
Total	**544**	**64**

Each partner was allotted a number of countries and was asked to clean the addresses, e.g. to take out doubles when for instance the same organisation was listed twice but under a slightly different name. This method resulted in a list of 543 PROs. The number of PROs for large countries (France, Germany, Italy, Spain and UK) was set at about 50 PROs, while for the other countries PROs were randomly selected from the list, dependent - in principle and roughly - on the size of the economy of that country.

10.1.5 Item non-response

Table 30 exhibits the number of visits of respondents of the survey web-site, the number of mailed questionnaires that were received, the responses that contained information (called the useable responses), the completion rates per question category (i.e. the percentage of question answered of the total) and other information from the survey. The average response rate is 50% or lower, which means that on average when a respondent submitted a usable completed questionnaire this person answered only 1 out of 2 questions (or less than that). In general Q4 and Q5 received – as expected – the highest response rates, the other more factual questions asking for concrete numbers or distribution in shares, received a lower response rate due to the fact that a respondents often do not have the requested information at hand. Also during the interviews the respondents were either reluctant to answer these questions or they could not provide the requested detailed distribution in percentages. The majority of respondents highly value the possibility offered to receive the summary of the study.

The final response rate for companies is 5.6% and for PROs 9.6%.

Table 30: Response rates per type of question

	Companies	**Public research organisations (PROs)**
Unique IP numbers that visited the survey web site	122	78
Response by mail	15	7
Valid (usable) Reponses	**103**	**64**
Completion rate per question in the Survey		
Q1	74%	45%
Q2	31%	39%
Q3	39%	28%
Q4	73%	58%
Q5	65%	43%
Average completion rate	51%	43%
Wants to receive summary	61%	85%

Source: EU Survey on Cost of Research (2011)

In general the response rate of a survey is an indicator of the respondents' willingness to participate in a survey. High response rates are seldom seen in business surveys.

Table 31 exhibits some categories and numbers of responses received. Several respondents have submitted the survey by mail, but most have reacted by clicking on the URL of the first web page of the survey. The information from the survey gives an insight in the efforts the respondents have taken after 'clicking the URL' of the web-survey. Some of them never gave any answer. Some 'free riders' only clicked the box asking for a summary of the study, without answering any question. Most respondents only answered the qualitative questions. Only a very small number of respondents completed the questionnaire fully, including the quantitative costs questions.

For the statistical analysis of the company survey, missing values were replaced by observations' of industry average. Given the exiguous number of observations (103 companies) and the (likely) random distribution of missing values there was a high risk of small sample size on some questions; substituting missing values with sector averages seemed therefore a sound and suitable procedure. On the one hand it does not influence too much "average" results, on the other hand it enables all the actual responses to be kept in the sample. We did this for all the quantitative variables in the companies' survey (i.e., variables expressed as numbers), including those where judgements were expressed as scores. In the case of PROs, the problem of missing values still remains, since the set of PROs is more heterogeneous than the set of companies and, it is impossible to apply average imputation of any kind. Thus, the PROs analysis was run under sample size varying according to the specific response rate of single questions.

Our conclusion is that the questionnaire was too complicated, too long, asking for too much quantitative information and too much detail, but that the subject is interesting for most of the people contacted, since many have asked to receive the summary. The questions on the cost structure (Q2) and cost developments (Q3) received low completion rates, and the completion rate of the question about cost structure over five years (Q2B) and the detailed cost development of capital costs was miserable.

Disappointing, and surprising was the cooperation of PROs, since the completion rates are much lower than for companies and only one responding PRO completed the whole questionnaire. At the start of the survey the project team expected the highest response from PROs because they have a closer relation with public organisations and policy makers.

Table 31: Response rates by category

Companies	Number	Average Completion rate
Reponses by mail	15	60%
Unique visitors web survey	122	n.a.
Free riders	7	0%
All usable responses	103	51%
Respondents with completion rate > 80%	31	89%
PROs		
Reponses by mail	7	37%
Unique visitors web survey	78	n.a.
Free riders	18	0%
All useable Reponses	64	43%
Respondents with completion rate >80%	1	91%

In short, at the start of the survey, when the first responses were received end of December 2010, the response rate was extremely low. Since the increased activities such as refusal conversion and reminding respondents by telephone (see above), the response rate increased considerably, notwithstanding the fact that it was a time consuming task to get useful responses. Often respondents ticked the box in order to get a summary and then quitted the survey very soon without giving any or very few answers.

10.2 Case study approach and case study selection

The case studies cover the qualitative study of 16 European and 5 non-European firms and 16 European PROs. Case studies were performed to provide further micro-level evidence on important topics of a more qualitative nature that could not be tackled adequately by the survey.

10.2.1 The interview guideline

In the first step a core interview guideline was developed which covers a set of common questions addressed by the interviews.

Interview Guideline

1. Development of R&D costs
How have the components of R&D costs (wage, capital, material, etc.) developed in the last five years?
Have these been steady-state changes or disruptive changes?
How do you expect that R&D costs will change in the next five/ten years?

2. Drivers for the costs of R&D
What have been the main drivers for the costs of R&D? (e.g. regulation, IT, market competition, complexity of the process, funding, etc.)?
How important are spillovers in your company? Do spillovers have an impact on the costs of R&D?
What effect has the market environment (market share, price competition, etc.) on the costs of R&D?

3. Management strategy
What is the relative importance of costs of R&D (compared to access to labour, closeness to market, get ideas from outside, etc.) for defining your research strategy?
Is your management focus more on cost control (salaries, outsourcing, etc.) or on increasing the output and outcome of R&D (licensing, new business models, etc.)?
What have you done in the past years to contain the costs of R&D in our company (outsourcing, strategic alliances, terminating projects at an early stage, platforms, new business models, etc.)?
What is the relative importance of costs of R&D for defining your R&D budget?
Have you closed any R&D locations in the past? What have been the reasons?
To what extent do changes in the costs of R&D had /may have an impact on location decisions? In which locations do your intend to expand your R&D activities in the future?
What are other strategies you may pursue to contain the costs of R&D in the future?

4. R&D cost indicators
How do you measure the costs of research?
How to you define and measure R&D productivity? Do you think research productivity has grown?
Why is that (e.g. because technology becomes more complex, …)?

5. Role of public policy? How do FP projects impact the costs of R&D? How do other

policies (tax incentives, risk capital, support the inflow of R&D personnel, etc.) impact the costs of R&D in your company?

In addition to these generic questions specific questions were posed to investigate cost drivers and reasons for trends, according to sector characteristics or organisational strategies, and which a firm or PRO might identify as relevant to R&D costs.

10.2.2 The selected companies and Public Research Organisations

The selection of the firms and PROs was guided by two criteria:

i) to have a good coverage of countries across Europe, and
ii) to have an adequate mix of organisations regarding the sector and organisational strategies.

Existing relationship of team members were used to get a contact to interesting organisations and to identify relevant experts within the firms and PROs.

The identification and selection of firms started in June 2010 after the first version of the survey questionnaire had been prepared. Firms were identified in consultation with the client using a selection of companies across more significant R&D intensive sectors in the EU and UK R&D scoreboards and using additional background literature. One criterion taken into account in nominating companies for the selection process was knowledge about special circumstances or step changes that might be considered interesting or illuminating from a cost perspective (e.g. R&D relocation factors). Having a range of technology and R&D activities represented was also a consideration. The above criteria were intended to enable qualitative information to clarify and illustrate any issues or data emerging from the survey

In addition, the team has conducted background research on these and a wider range of organisations in order to prepare for the interviews, to focus discussion on key issues and to enable further discussions after the preliminary analysis of cases, for clarification and to prepare for a discussion with expert about implications for industry and policy.

The final list of selected firm and PRO cases and the position of the interviewed experts is disclosed in the following table:

Table 32: Overview of case study organisations.

Name	**Location**	**Sector**	**Position of the interviewee(s)**
Companies			
Boehringer Ingelheim	Germany/ Austria	Pharma/ Chemistry	Administrative Director of the R&D unit
Software company (anonymous)	Central Europe	Software	Research Management Control; Research Project Officer
Bosch	Germany	Automotive	Director Coordination Technology
Homag	Germany	Machinery	Director R&D Lab
Avio	Italy	Aerospace	Head of RTD
Eni	Italy	Energy	Vice President Technology planning R&D Department

Bracco	Italy	Pharmaceuticals	Director Research Centre
GDF Suez	France	Energy	Director Research Center; Research Program Management
Rhodia	France	Chemicals	Vice President R&D; Head of Finance R&D
Fagor Electro-domesticos	Spain	Household Goods	R&D Director
Motorola	US	Telecommuni-cations	Director of Research
Medtronics	US	Electronics	Vice President of Innovation Excellence
Tellabs	US	Electronics	Research Fellow
Texas Instruments	US	Semiconductor	Senior Research Fellow
Ruijie Networks	Beijing, China	Telecommunicat ions	Chief Executive Officer
DSM	The Nether lands	Chemicals	R&D Manager
Philips	The Nether lands	Electronics	R&D Control
TELENOR	Norway	Telecommunicat ions	Research Director
Astra Zeneca	UK	Pharmaceuticals	Portfolio Manager
BBC	UK	TV broadcasting and multimedia content	R&D Manager
Rolls-Royce	UK	Aerospace	Research Director
PROs			
Bay Zoltan Foundation for Applied Research	Hungary	Diverse	Director of the institute
Institute for Manufacturing Technologies (IMT) of the Forschungs-zentrum Karlsruhe (KIT)	Germany	Manufacturing and Materials	Administrative Director; Technology Planning
German Aerospace Center (DLR)	Germany	Aerospace	Strategic Development Department
Institute of Bioprocessing and Analytical Measurement Techniques (IBA)	Germany	Biology	Director of the Institute

Austrian Institute of Technology (AIT)	Austria	Diverse	Management Control
ELETTRA	Italy	Physics, Multidiscipl.	Chief Executive Officer
IST, National Institute of Cancer Research	Italy	Health, Biomedicine	Scientific Director
INRIM	Italy	Measurement and Material	President
INRA	France	ICT	Deputy Director General; Financial Director
Labein Tecnalia	Spain	Diverse	Research Director
CSTB	France	Computer Science and Construction	Head of Research Unit
SINTEF	Norway	Industry	Accounting and Finance
VTT	Finland	Industry	Program Management
Moredun Research Institute (MRI)	UK	Animal Health	Scientific Director
Technology Partners Foundation (TPF)	Poland	Research and technology services	Chief Executive Officer
National Physical Laboratory	UK	Physics	Business development manager

10.3 Methodological lessons for future surveys and studies

Within the COST project the research team has combined quantitative and qualitative methodologies. Both approaches complement each other. The case studies provide more detail and understanding about the drivers of research costs and related managerial actions. They provide opportunity to investigate more complex questions in particular contexts and to develop some exploratory hypotheses and relationships. But generalisation from cases must always be carefully considered and it is the exceptions and specifics of cases which might be revealing and important. In comparison, the survey offers cross-industry findings and a more representative impression of trends. The findings of the survey have not been compared directly and systematically with cases in this report, and will be difficult because of the survey response rate, the selection of cases, and the open-ended and broad approach adopted towards cases, but findings from the survey (such as the development of cost elements and cost drivers) are confirmed generally by the case studies.

In general, in both cases, the survey and case studies, respondents and interviewees were very reluctant to give commercially sensitive information. They may be willing to discuss trends and issues and accounting practices but not percentage trends in company expenditures. Company specific data, such as Q4 and Q5 in the survey, is problematic.

A valuable lesson for further research on this subject (and industrial R&D more widely) is to conduct case studies first and use the insight and information to better prepare a follow-up survey (i.e. the reverse procedure to this study).

With respect to the survey, the following lessons can be drawn for conducting a similar exercise in the future:

- For future surveys, avoiding detailed questions (for exact amounts in Euros or distribution in percentages) could increase the response.
- The length of the questionnaire with 8 pages was regarded as too long;
- Contact details of persons for the R&D Scoreboard and PRO address list could reduce the resources needed for the survey.

Generally, the definition of research costs as product of volume and price proofed to be successfully. While we have asked companies to assess whether the evolution of different research cost components was primarily caused by volume or price effects it might be also helpful, that companies assess for each component the development of both price and volume effects. For further lessons and research needs see also chapter 8.5.

11 Literature

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12 List of the members of the Expert Group

- Vladimir Albrecht, Technology Centre of the Academy of Sciences, CZ
- Jan Andersen, President, EARMA, UK
- Jérôme Billé, Association des Structures de Recherche Contractuelle – ASRC, France
- Thomas Durand, Professor at Ecole Centrale, Director of Strategy & Technology Research Lab, France
- Richard Granger, Granger, UK
- Frank Heemskerk, Research & Innovation Management Services, Belgium
- Christopher Hull, General Secretary EARTO, Brussels
- Tomasz Kosmider, Director TPF, Poland
- Jos Leijten, JIIP & TNO, The Netherlands
- Terttu Luukkonen, EFTLA, Finland
- Peter Matthews, IMIG AG, Germany
- Sonja Marjanovic, RAND Europe, UK

Appendix: The survey questionnaires

Survey on Costs of Research and Development in Companies

The European Commission has contracted this survey, following a public tendering procedure, to UNU-MERIT, an international research and training organisation with specialist knowledge and considerable experience with surveys of this kind. The purpose of this study is to understand better trends in the costs of R&D and their drivers. Part of the study is a questionnaire which has been designed to collect factual evidence about past, current and anticipated developments in research costs.

Your company belongs to the 1000 largest R&D spenders among European companies or to the 1000 largest R&D spenders worldwide. Your company also participates in ``The EU Industrial R&D investment SCOREBOARD´´ and its surveys. These surveys focus on the current amount and intensity of R&D, the global leaders and the growth in the R&D efforts. This questionnaire goes a step further and targets the same enterprises in order to unveil the drivers of the cost of research in EU and in other locations. With your feedback the EU Industrial R&D investment survey´s might be enriched by new issues regarding the containment of the cost of research.

All information gathered will be treated strictly confidentially and neither individuals nor organisations will be identifiable on the basis of their responses as the data collection will be anonymised[1] by UNU-MERIT. This questionnaire can be completed within 30 minutes. In appendix B you find a glossary of terms used in the survey. All questions refer to the consolidated company (or corporation) rather than to a particular division or facility.

I would appreciate your response by the end of February 2011, preferably by using the questionnaire on our website at: http://survey.merit.unu.edu/corcom/

If you prefer to use a paper based form, please return it - using the enclosed envelope - to: Dr. Huub Meijers, UNU-Merit, Research Group II, Keizer Karelplein 19, 6211TC, Maastricht, The Netherlands. We thank you in advance for your kind attention and collaboration with this important work which will ultimately be helpful in shaping the future EU RTD policy.

Please tick here ☐ if you wish to receive the summary of the survey results

Company Name:	
Your name:	
Your E-mail:	
Your phone number:	
Job title:	

[1] See the Disclaimer on page 9.

1. Location of R&D[2]

Please estimate the geographic distribution of your company's in-house R&D activity over the following world regions, now, five years ago, and in five years?

R&D carried out in:	**Present distribution**	**Distribution 5 years ago**	**Distribution 5 years from now**
a) EU15[3]	%	%	%
b) other EU27[4]	%	%	%
c) Switzerland	%	%	%
d) Other European countries[5]	%	%	%
e) US and Canada	%	%	%
f) Japan	%	%	%
g) China	%	%	%
h) India	%	%	%
i) Russia	%	%	%
j) Other countries	%	%	%
Total	**1 0 0 %**	**1 0 0 %**	**1 0 0 %**

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[2] See Appendix B at page -10- for a glossary of terms

[3] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom.

[4] Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovak Republic and Slovenia.

[5] Albania, Bosnia and Herzegovina, Croatia, Georgia, Iceland, Kazakhstan, Liechtenstein, Republic of Macedonia, Montenegro, Norway, Serbia and Turkey.

2. Cost composition of R&D[6]

What is the current composition of your R&D costs in your main R&D location (worldwide) please, state country in question (see below).
If applicable, what is the current composition of your R&D costs in the most dynamic region (stating the country) compared to this composition at your main R&D location.

Example of most dynamic region is the one with the highest (expected)rate of economic growth or the best opportunities for the company.

	Main world region	*Most dynamic region*
State country of location		
b) R&D Wage costs:	%	%
c) Capital costs:	%	%
c.1) ICT costs	%	%
c.2) Machines and equipment (excl. ICT)	%	%
c.3) Research infrastructures, incl. maintenance	%	%
d) Costs of financing	%	%
e) Materials and supplies	%	%
f) Purchased R&D services (incl. subcontracting and outsourcing)	%	%
g) Costs of obtaining patents	%	%
h) Other costs, please specify		
	%	%
TOTAL	**100%**	**100%**

[6] Please see page 10 for a glossary of terms

3. Cost developments

3A. Please estimate approximately how each of the following costs for R&D financed by your company has changed in the past five years.

In the first column please give the total percentage increase of these costs between 5 years ago and now (and not the average per year over this period). Enter cost decreases as a negative number. Also try to distinguish between volume effects or price effects but not both. Volume effects are e.g. costs increases due to an increase in the number of researchers, price effects are e.g. costs increases due to an increase of the wage cost per researcher.

	%change of costs	Price effect	Volume effect
		Tick one box per row	
a) Total R&D costs	☐☐☐ %	☐	☐
b) R&D wage Costs	☐☐☐ %	☐	☐
c) Capital Costs	☐☐☐ %	☐	☐
c.1) ICT costs	☐☐☐ %	☐	☐
c.2) Machines and equipment	☐☐☐ %	☐	☐
c.3) R&D infrastructures	☐☐☐ %	☐	☐
d) Costs of financing	☐☐☐ %	☐	☐
e) Materials and supplies	☐☐☐ %	☐	☐
f) Purchased R&D services (incl. subcontracting and outsourcing)	☐☐☐ %	☐	☐
g) Costs of obtaining patents	☐☐☐ %	☐	☐
h) Other costs, please specify			
	☐☐☐ %	☐	☐

3.B. Please estimate approximately how each of the following costs for R&D financed by your company will have changed <u>over 5 years time</u>.

	%change of costs	Price effect	Volume effect
		Tick one box per row	
a) Total R&D costs	☐☐☐ %	☐	☐
b) R&D wage Costs	☐☐☐ %	☐	☐
c) Capital Costs	☐☐☐ %	☐	☐
c.1) ICT costs	☐☐☐ %	☐	☐
c.2) Machines and equipment	☐☐☐ %	☐	☐
c.3) R&D infrastructures	☐☐☐ %	☐	☐
d) Costs of financing	☐☐☐ %	☐	☐
e) Materials and supplies	☐☐☐ %	☐	☐
f) Purchased R&D services (incl. subcontracting and outsourcing)	☐☐☐ %	☐	☐
g) Costs of obtaining patents	☐☐☐ %	☐	☐
h) Other costs, please specify			
	☐☐☐ %	☐	☐

3C. Please specify approximately the number of employees in your company who work directly or indirectly on R&D activities now, five years ago and in five years? First in number of employees, second in full time equivalents.

	present situation	five years ago	expected in 5 years
Number of employees:			
a) researchers, technicians and other staff	☐☐☐☐☐	☐☐☐☐☐	☐☐☐☐☐
In fulltime equivalents:			
d) researchers, technicians and other staff	☐☐☐☐☐	☐☐☐☐☐	☐☐☐☐☐

4. Drivers of the costs of R&D

Please rate the following drivers in terms of their importance for the cost of R&D in your company now and in five years time.
*(1 = Very important in **cost reductions**, 2=Somewhat important in **cost reductions**, 3=Neutral, 4=Somewhat important in **cost increases**, 5 = Very important in **costs increases**)*

	Now					In five years time				
	1	2	3	4	5	1	2	3	4	5
a) Availability of qualified researchers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
b) Regulation of the labour market for scientists	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
c) Regulation of the product market	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
d) Complexity of the R&D process	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
e) Duration of R&D projects	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
f) Scale of R&D projects	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
g) Location of R&D projects	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
h) Technological efficiency in the R&D process	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
i) Cost of patenting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
j) Litigation or threat of litigation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
k) Environmental legislation/regulation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
l) Possibilities of joining collaborative R&D projects	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
m) Aligning R&D opportunities with business strategies (Roadmapping)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
o) Other, please specify:										
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

5. R&D management, strategies and R&D cost indicators

5A. Please indicate the importance of the following methods and strategies to contain R&D costs in your company during the last 5 years.

	Not important	Somewhat important	Very Important
a) Improving worker productivity (e.g. incentive schemes, better facilities, new technologies)	☐	☐	☐
b) Expanding R&D activity in lower labour cost countries	☐	☐	☐
c) R&D outsourcing, delegation of R&D to suppliers and customers	☐	☐	☐
d) Applying for subsidies	☐	☐	☐
e) Applying for tax incentives	☐	☐	☐
f) Operating R&D as a profit centre or as a business (including strategic exploitation of IP)	☐	☐	☐
g) Collaborative networks, strategic alliances and specialisation of R&D activity	☐	☐	☐
h) Acquisition of companies with relevant expertise to avoid risks of R&D investments	☐	☐	☐

5B. R&D Cost indicators

a) If applicable, what is your industry's widely accepted indicator of R&D costs? (e.g. the cost of a new drug, the total cost of R&D to generate a patent, the cost of R&D up to prototype stage)

b) What is the total percentage change shown by the *industry* indicator over the last 5 years? (not the annual % change) %

c) Does your company use this indicator to analyse or compare R&D costs? ☐ **Yes** ☐ **No**

d) What is the total percentage change shown by the indicator for *your company* over the last 5 years? (not the annual % change) %

5C. What is the role of the following factors in determining the R&D budget of your company?

	not important	somewhat important	very important
a) Cost of R&D	☐	☐	☐
b) a fixed percentage of turnover	☐	☐	☐
c) Strategic R&D decisions	☐	☐	☐

Other:

5D. Please assess how the costs of producing a unit of the following outputs have increased over the last 5 years? (total % change). Use a negative sign to indicate percentage decreases in costs.

a) Writing a refereed scientific publication ___ %

b) Generating a patentable application opportunity including all stages from concept to application ___ %

c) Development of a prototype or new technological solution ___ %

Thank you very much for your cooperation

Appendix A. The Survey and Privacy

Your enterprise participates in "The EU Industrial R&D investment SCOREBOARD" surveys. These surveys focus on the current amount and intensity of R&D, the global leaders and the growth in the R&D efforts. This questionnaire goes a step further and targets the same enterprises that participate in the EU R&D SCOREBOARD survey in order to unveil the drivers of the cost of research in EU and in other locations.

All information gathered will be treated strictly confidentially and neither individuals nor organisations will be identifiable on the basis of their responses as the data collection will be anonymised by UNU-MERIT. The data collection will be anonymised using micro aggregation, disclosing only statistical aggregates (e.g. averages or means) of the answers of a group of enterprises together.

This anonymised data collection will be used to test a number of hypotheses and to get an insight in the future geographical dispersion of the R&D efforts of the main actors in EU and elsewhere. With these hypotheses this project aims to single out the main drivers of the cost of research. The project team looks for possible candidate costs drivers in three groups of variables: human competences, industrial structure and the environment in which R&D is carried out.

With the results of this survey and additional in-depth case studies more information on R&D behaviour will become available. This information can be used by policy makers to improve the environment, making it more conducive to knowledge creation, innovation and as a consequence economic growth and prosperity.

For further information on the survey and privacy please contact either Dr. Huub Meijers or Theo Dunnewijk.

Meijers@merit.unu.edu Telephone: +31 43 3884406
Dunnewijk@merit.unu.edu Telephone: +31 43 3884401/+ 31 43 6011473

Appendix B. Glossary of terms

R&D:

For the purpose of this questionnaire R&D is defined as the total amount of R&D financed by your company (as typically reported in the annual accounts, exclusive of external (private and public) sources).

Wage costs:

Comprise annual wages and salaries and all associated costs or fringe benefits, such as bonus payments, holiday pay, contributions to pension funds and other social security payments, payroll taxes, etc.

Capital Costs:

In measuring capital costs major expenditure on tools, instruments, prototypes and buildings are included. Occasionally, the R&D term of a fixed asset may be known at the time of acquisition. In this case the appropriate portion of the expenditure for the acquisition of the asset should be attributed to R&D capital costs. When the R&D term of the asset is not known and a fixed asset will be used for more than one activity and neither the R&D nor any of the non-R&D activities predominates (e.g. computers and associated facilities; laboratories used for R&D, testing, and quality control), the costs should be prorated between R&D and other activities. This proportion could be based on numbers of R&D personnel using the facility, compared to total personnel, or on administrative calculations already made (e.g. the R&D budget may be charged a certain portion of the capital cost; a certain proportion of time or floor space may be assigned to R&D).

Cost of financing:

The cost financing R&D expenditures fall into this category. Opportunity costs or internal rates of return do not belong to this category.

Number of employees: Researchers, Technicians and other supporting staff:

The number of employees is the total average employees or yearend employees if average is not stated.

Full time equivalent employees (FTE)

One full-time equivalence (FTE) unit may be thought of as one person-year. A person who spends 30% of his time on R&D and the rest on other activities during the one-year reporting period should be considered as 0.3 FTE. If a full-time R&D worker is employed for only six months during the one-year reporting period, this results in a 0.5 FTE.

Regulation of labour market and product markets:

The costs incurred in order to comply with government regulations with regarding the labour market as well as the product market falls into this category. Attracting employees or introducing new products is often regulated and these regulations come with additional costs. An example of these costs might be the additional cost of employing a foreign scientist compared to a employing a local scientist.

Complexity of the R&D process:

R&D might become more complex due to an increasing number of variables to be taken into account or more technologies used in the R&D process or due to a shift in the R&D paradigm. Examples are the environmental effects that are now taken into account in crop protection research and the shift toward biotechnology in pharmaceutical research.

Technological efficiency of the R&D process:

Efficiency and effectiveness should be distinguished: An inefficient technology used in R&D in an appropriate project might be more efficient that an efficient technology in an inappropriate project. Technological efficiency of the R&D process measures the output of the R&D process in relation to the kind and size of the technologies used in the R&D process.

Environmental legislation and regulation:

The costs incurred in environmental legislation and regulation as far as it affects the cost of R&D, also the effects on the cost of R&D of environmental and sustainability issues due to consumer interests and brought forward by pressure groups.

Collaborative R&D projects:

Collaborative R&D projects serve multiple purposes: The need to collaborate might come forward from generic projects as well as targeted R&D projects. This might affect the cost of R&D in the short run and in the long run differently.

Survey on Costs of Research and Development in Public Research Organisations

The European Commission has contracted this survey, following a public tendering procedure, to UNU-MERIT, an international research and training organisation with specialist knowledge and considerable experience with surveys of this kind. The purpose of this study is to understand better trends in the costs of R&D and their drivers. Part of the study is a questionnaire which has been designed to collect factual evidence about past, current and anticipated developments in research costs.

This questionnaire has been sent to the 500 main European non-university Public Research Organisations, therefore your organisation is kindly invited to take part in this survey.

All information gathered will be treated strictly confidentially and neither individuals nor organisations will be identifiable on the basis of their responses as the data collection will be anonymised[1] by UNU-MERIT.

This questionnaire can be completed within 30 minutes. In appendix B you find a glossary of terms used in the survey.

If you prefer to use a paper based form, please return it - using the enclosed envelope - to:
Dr. Huub Meijers, UNU-Merit, Research Group II, Keizer Karelplein 19, 6211TC, Maastricht, The Netherlands.

I would appreciate your response by the end of February 2011, preferably by using the questionnaire on our website at: http://survey.merit.unu.edu/corpro/

I thank you in advance for your kind attention and collaboration with this important work which will ultimately be helpful in shaping the future EU RTD policy.

Please tick here ☐ if you wish to receive the summary of the survey results

Company Name:	
Your name:	
Your E-mail:	
Your phone number:	
Job title:	

[1] See the Disclaimer on page 9.

1. General information

a) How much of the total budget is publicly funded? %

b) Is your organisation publicly owned? ☐ Yes ☐ No

If YES, c) what is the approximate share of public ownership? %

Please report annual data for most recent year:	€ Bil.	Mil.	Thou.
d) Current total R&D budget			
e) Current core[2] R&D budget			
f) Capital expenditures[3]			
g) Other expenditures			
h) All personnel costs			

i) Number of researchers

j) Researchers in full time equivalents

k) Number of total staff

l) Total staff in fulltime equivalents

If applicable:

m) Number of ISI publications[4] (average of last 3 years)

n) Number of EPO[5] patent applications (average of last 3 years)

o) Number of USPTO[6] patent applications (average of last 3 years)

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[2] Core budget is understood as the regular annual amount of finance provided by the government or other patron for the purpose of carrying out intra and extramural R&D.
[3] Capital includes facility, equipment, machinery, and information systems.
[4] Publications that are or going to be included in the ISI Web of Knowledge collection (Thomson Reuters)
[5] European Patent Office
[6] U.S Patent Office

2. Cost composition of R&D[7]

What is the current composition of your R&D costs?

a) Total R&D costs	%	
b) R&D *wage costs*	%	
c) Capital costs:	%	
c.1) ICT costs		%
c.2) Machines and equipment (excl. ICT)		%
c.3) Research infrastructures, incl. maintenance		%
d) Costs of financing	%	
e) Materials and supplies	%	
f) Purchased R&D services (incl. subcontracting)	%	
g) Patent application costs	%	
h) Other costs, please specify:		
	%	
Total	**1 0 0** %	

[7] See Appendix B at page 10 for a glossary of terms

3. Cost developments

3A. Please estimate approximately how each of the following R&D costs have changed <u>in the past five years</u>.

In the first column please give the <u>total percentage increase</u> of these costs between 5 years ago and now (and not the average per year over this period). Enter cost decreases as a negative number. Also try to distinguish between volume effects or price effects not both. Volume effects are e.g. costs increases due to an increase in the number of researchers, price effects are e.g. costs increases due to an increase of the wage cost per researcher.

	%change of costs	Price effect	Volume effect
		Tick one box per row	
a) Total R&D costs	☐☐☐ %	☐	☐
b) R&D wage Costs	☐☐☐ %	☐	☐
c) Capital Costs	☐☐☐ %	☐	☐
c.1) ICT costs	☐☐☐ %	☐	☐
c.2) Machines and equipment	☐☐☐ %	☐	☐
c.3) R&D infrastructures	☐☐☐ %	☐	☐
d) Costs of financing	☐☐☐ %	☐	☐
e) Materials and supplies	☐☐☐ %	☐	☐
f) Purchased R&D services (incl. subcontracting and outsourcing)	☐☐☐ %	☐	☐
g) Costs of obtaining patents	☐☐☐ %	☐	☐
h) Other costs, please specify			
☐	☐☐☐ %	☐	☐

3B. Please estimate approximately how each of the following R&D costs will have changed over <u>five years time</u>. (See for an explanation question 3A)

	%change of costs	Price effect	Volume effect
		Tick one box per row	
a) Total R&D costs	☐☐☐ %	☐	☐
b) R&D wage Costs	☐☐☐ %	☐	☐
c) Capital Costs	☐☐☐ %	☐	☐
c.1) ICT costs	☐☐☐ %	☐	☐
c.2) Machines and equipment	☐☐☐ %	☐	☐
c.3) R&D infrastructures	☐☐☐ %	☐	☐
d) Costs of financing	☐☐☐ %	☐	☐
e) Materials and supplies	☐☐☐ %	☐	☐
f) Purchased R&D services (incl. subcontracting and outsourcing)	☐☐☐ %	☐	☐
g) Costs of obtaining patents	☐☐☐ %	☐	☐
h) Other costs, please specify			
☐	☐☐☐ %	☐	☐

4. Drivers of the costs of R&D

Please rate the following drivers in terms of their importance in affecting the cost of R&D in your organisation now and in five years time.

*(1 = Very important in **cost reductions**, 2=Somewhat important in **cost reductions**, 3=Neutral, 4=Somewhat important in **cost increases**, 5 = Very important in **costs increases**)*

	Now					Over five years time				
	1	2	3	4	5	1	2	3	4	5
a) Availability of qualified researchers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
b) Regulation of the labour market for scientists	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
c) Coordination costs in EU funded projects	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
d) Complexity of the R&D process	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
e) Duration of R&D projects	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
f) Scale of R&D projects	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
g) Costs for communicating and reporting research results for accountability purposes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
h) Costs of applying for research grants (national and international)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
i) Cost of patenting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
j) Litigation or threat of litigation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
k) Environmental legislation/regulation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
l) Public policy measures to support mobility of researchers	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
m) Public policy measures to support the commercialisation of research results (e.g. spin-offs, technology transfers)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
n) Other, please specify:	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

5. R&D cost indicators, finance and budget

5A. Please indicate the importance of the following methods and strategies to contain R&D costs in your organisation during the last 5 years.

	Not important	Somewhat important	Very Important
a) Improving worker productivity (e.g. incentive schemes, better facilities, new technologies)	☐	☐	☐
b) Expanding R&D activity in lower labour cost countries	☐	☐	☐
c) R&D outsourcing, delegation of R&D to suppliers and customers	☐	☐	☐
d)) Eliminating less important R&D activities	☐	☐	☐
e) Establishment of organisational units aiming to commercialise research results (technology transfer office, exploitation of IP, spin-off creation, Joint Ventures, etc.)	☐	☐	☐
f) Operating R&D as a profit centre or as a business (including strategic exploitation of IP)	☐	☐	☐
g) Collaborative networks, strategic alliances and specialisation of R&D activity	☐	☐	☐
h) Acquisition of companies with relevant expertise to avoid risks of R&D investments	☐	☐	☐

5B. R&D cost indicators

a) If applicable does your organisation use an indicator to measure R&D costs (e.g. the cost to generate a patent, the cost of R&D up to prototype stage, the cost to produce a scientific publication)? ☐ **Yes** ☐ **No**

If NO skip sub-questions b and c and go to d)

b) Please specify (the most important) indicator:

c) What is the total percentage change shown by this indicator for your organisation *over the last 5 years*? (not the annual % change) ☐☐☐ %

d) Please assess approximately how the costs of producing a unit of the following outputs have increased over the last 5 years? (total % change, not the annual % change). Use a negative sign to indicate percentage decreases in costs.

- i) Writing a scientific publication (according to your own quality standards) ☐☐☐ %
- ii) Generating a patentable application opportunity including all stages from concept to application (if this is an important goal for your organisation) ☐☐☐ %
- iii) Development of a prototype or new technological solution (if this is an important goal for your organisation) ☐☐☐ %

5C. Financing of core R&D budget

a) Is your core R&D budget provided by a public institution? ☐ **Yes** ☐ **No**

If NO skip to the end of the questionnaire

How is the core R&D budget determined?

b) It is negotiated with the public owner based on strategic goals ☐ **Yes** ☐ **No**

c) It is based on a performance agreement/contracts ☐ **Yes** ☐ **No**

d) It is based on performance indicators ☐ **Yes** ☐ **No**

e) It is based on the size of the organisation (e.g. number of staff) ☐ **Yes** ☐ **No**

f) Other ways, please specify:

Thank you very much for your cooperation

Appendix A. The Survey and Privacy

All information gathered will be treated strictly confidentially and neither individuals nor organisations will be identifiable on the basis of their responses as the data collection will be anonymised by UNU-MERIT. The data collection will be anonymised using micro aggregation, disclosing only statistical aggregates (e.g. averages or means) of the answers of a group of enterprises together.

This anonymised data collection will be used to test a number of hypotheses and to get an insight in the future geographical dispersion of the R&D efforts of the main actors in EU and elsewhere. With these hypotheses this project aims to single out the main drivers of the cost of research. The project team looks for possible candidate costs drivers in three groups of variables: human competences, industrial structure and the environment in which R&D is carried out.

With the results of this survey and additional in-depth case studies more information on R&D behaviour will become available. This information can be used by policy makers to improve the environment, making it more conducive to knowledge creation, innovation and as a consequence economic growth and prosperity.

For further information on the survey and privacy please contact either Dr. Huub Meijers or Theo Dunnewijk.

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Appendix B. Glossary of terms

R&D:

For the purpose of this questionnaire R&D is defined as the total amount of R&D financed by your organisation (as typically reported in the annual accounts, exclusive of external (private and public) sources).

Wage costs:

Comprise annual wages and salaries and all associated costs or fringe benefits, such as bonus payments, holiday pay, contributions to pension funds and other social security payments, payroll taxes, etc.

Capital Costs:

In measuring capital costs major expenditure on tools, instruments, prototypes and buildings are included. Occasionally, the R&D term of a fixed asset may be known at the time of acquisition. In this case the appropriate portion of the expenditure for the acquisition of the asset should be attributed to R&D capital costs. When the R&D term of the asset is not known and a fixed asset will be used for more than one activity and neither the R&D nor any of the non-R&D activities predominates (e.g. computers and associated facilities; laboratories used for R&D, testing, and quality control), the costs should be prorated between R&D and other activities. This proportion could be based on numbers of R&D personnel using the facility, compared to total personnel, or on administrative calculations already made (e.g. the R&D budget may be charged a certain portion of the capital cost; a certain proportion of time or floor space may be assigned to R&D).

Cost of financing:

The cost financing R&D expenditures fall into this category. Opportunity costs or internal rates of return do not belong to this category.

Number of employees: Researchers, Technicians and other supporting staff:

The number of employees is the total average employees or yearend employees if average is not stated.

Full time equivalent employees (FTE)

One full-time equivalence (FTE) unit may be thought of as one person-year. A person who spends 30% of his time on R&D and the rest on other activities during the one-year reporting period should be considered as 0.3 FTE. If a full-time R&D worker is employed for only six months during the one-year reporting period, this results in a 0.5 FTE.

Regulation of labour markets:

The costs incurred in order to comply with government regulations with regarding the labour market fall into this category. Attracting employees or introducing new products is often regulated and these regulations come with additional costs. An example of these costs might be the additional cost of employing a foreign scientist compared to a employing a local scientist.

Complexity of the R&D process:

R&D might become more complex due to an increasing number of variables to be taken into account or more technologies used in the R&D process or due to a shift in the R&D paradigm. Examples are the environmental effects that are now taken into account in crop protection research and the shift toward biotechnology in pharmaceutical research.

Environmental legislation and regulation:

The costs incurred in environmental legislation and regulation as far as it affects the cost of R&D, also the effects on the cost of R&D of environmental and sustainability issues due to consumer interests and brought forward by pressure groups.