Investigation of ICT Firms' Decisions on R&D Investment

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Abstract
The formulation of a macroeconomic model applied to the analysis of EU Research and Development (R&D) funding strategies in Information and Communication Technology (ICT) under the PREDICT 2 project stipulates a specification of the transmission mechanism of R&D funding policy on firms' R&D expenditures. To enlighten the understanding of ICT firms' investment decisions, the effect of various firm characteristics on firms' R&D activities is analysed on a representative sample of ICT sector firms in 16 EU member countries. The analysis covers two aspects of the firms' R&D activity. Firstly, R&D engagement characterising those firms which undertake in-house R&D projects on a continuous basis, and secondly, R&D expenditure measured as the firms' in-house expenditure on R&D projects per employee. The report finds that reception of public funding is positively related to ICT firms' R&D activity. The relation between public funding and firms' R&D activity is found to depend on funding sources. The results also show that national and international diffusion of knowledge through firms' cooperation with other enterprises and through international trade plays an important role for firms R&D activity. Finally, the results suggest that substantial differences exist in firms' R&D activity across countries and sectors.
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Summary

The formulation of a macroeconomic model applied to the analysis of EU Research and Development (R&D) funding strategies in Information and Communication Technology (ICT) under the PREDICT 2 project stipulates a specification of the transmission mechanism of R&D funding policy on firms’ R&D expenditures. To enlighten the understanding of ICT firms’ investment decisions, the effect of various firm characteristics on firms’ R&D activities is analysed on a representative sample of ICT sector firms in 16 EU member countries. The analysis covers two aspects of the firms’ R&D activity. Firstly, R&D engagement characterising those firms which undertake in-house R&D projects on a continuous basis, and secondly, R&D expenditure measured as the firms’ in-house expenditure on R&D projects per employee.

This study provides valuable insight for the formulation of a macroeconomic model containing ICT R&D. Firstly, the report finds that reception of public funding is positively related to ICT firms’ R&D activity. The relation between public funding and firms’ R&D activity is found to depend on funding sources. The results show a positive relation between funding from national government and from the EU and ICT firms’ decision to engage in R&D. In contrast no statistical significant relation is found between local government funding and ICT firms’ R&D engagement. A positive relation was also found between funding from national government and from local government and ICT firms level of in-house R&D expenditures per employee, whereas no statistically significant relation was found between EU funding and ICT firms level of in-house R&D expenditures per employee. Such differences in the relation between public funding and ICT firms’ R&D expenditures indicates that special attention should be made to the modelling of linkages between different sources of public funding and private sector R&D expenditure levels.

Secondly, the results show that national and international diffusion of knowledge through firms’ cooperation with other enterprises and through international trade plays an important role for firms R&D activity. The report finds a positive relation between ICT firms’ R&D activity and the presence of cooperative innovative arrangements with other enterprises or institutions, the availability of R&D relevant information sources, and the degree of international competition. These firm characteristics are also found to be positively related to firms’ R&D activities in a sample of firms from all private sectors of the economy (including ICT).

Thirdly, the results suggest that substantial differences exist in firms’ R&D activity across countries and sectors. In the all sector sample a positive relation was found between firms’ belonging to the ICT or the Other High Technology industry groupings and their R&D activity. Furthermore the results show that ICT manufacturing firms had higher R&D activity than firms in ICT services. The country in which the firm is based is also found to be related to firms R&D activity. Such heterogeneity in firms R&D activity should be accommodated by a macroeconomic model applied to the analysis on R&D funding policy outcomes.
1. Introduction

This report focuses on the Research and Development (R&D) activities by firms in the Information and Communication Technologies (ICT) industry. The effect of various firm characteristics on firms' R&D activities is analysed on a representative sample of ICT sector firms in 16 EU member countries. The analysis covers two aspects of the firms' R&D activity. Firstly, R&D engagement characterising those firms which undertake in-house R&D projects on a continuous basis, and secondly, R&D expenditure measured as the firms' expenditure on in-house R&D projects per employee. The aim of the analysis is to identify those firm characteristics observed as important for firms' decision to engage in R&D and for determining the level of resources dedicated to R&D by the firms.

The research was carried out in the context of PREDICT 2, a research project co-financed by the Directorate General for Communications Networks, Content and Technology and JRC-IPTS. One of the objectives of PREDICT 2 is the development of a macroeconomic model allowing for the economic analysis of policy scenarios related to alternative ICT R&D funding policies. The formulation of the macroeconomic model stipulates a specification of the transmission mechanism of R&D funding on firms' R&D activities. In particular parameter settings to be used for calibrating behavioural equations in the model calls for a deeper investigation of ICT firm level R&D decisions. This is the main aim of this report.

In this report we examine R&D activities at firm level in the ICT industry from two perspectives. Firstly, we examine firms' R&D activity in a broad sample of firms from all sectors. This allows us to compare the R&D activity of the ICT industry firms relative to R&D activity of firms in other industries. Secondly, we examine the relation between firm characteristics and R&D activity of firms within the ICT industry, with further differentiation between the ICT sub-sectors ICT Manufacturing and ICT Services.

This research analyses R&D decisions within a representative sample of ICT firms identified in the CIS microdata. Firms are allocated to their sector at the four-digit level of the NACE Rev.2 classification using the OECD definition of the ICT industry (OECD, 2007). This approach means that no generalising assumptions or approximations were needed in the construction of the ICT sector aggregates. The analysis of firms R&D activity is conducted by applying an inferential econometric model to the data. This econometric technique has been well-established in the literature over the last decades. An overview of the methodology is provided in the Appendix and also discussed in more detail in the background IPTS report “Macroeconomic Modelling of Public Expenditures on Research and Development in Information and Communication Technologies”.

The findings presented in this report serve two main purposes. Firstly, they contribute to the understanding of factors, which may influence firms decisions related to their R&D investment. The second purpose of this report is to provide a base for the formulation of a macroeconomic model.

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1 The Institute for Prospective Technological Studies (IPTS) is one of seven research institutes of the European Commission’s Joint Research Centre (JRC).
3 For details about the application of the OECD definitions in this report see ‘Sources of data and sectoral aggregation’ chapter and Table 2 in the Appendix.
5 Forthcoming.
Parameter estimates from this report will be used to enlighten the understanding of ICT firms’ investment decisions. They will also be used for the setting of parameters in the behavioural equations of a CGE model which in later steps under the PREDICT 2 project will be employed for the economic analysis of policy scenarios related to ICT R&D funding.

The structure of the report is as follows. Section 2 presents the data used for the analysis, its processing and choice of sector aggregation. Furthermore section 2, presents the two types of firms’ R&D activity analysed in this study, R&D engagement and R&D expenditure and identifies firm characteristics potentially relevant for firms’ R&D decisions. Section 3 describes the inferential econometric model used to derive generalised information about the firms’ R&D behaviour. Results of the econometric analysis are discussed in section 4. Section 5 summarises the findings and concludes. More detailed information about data, model specifications and estimation techniques are described in the appendix.
2. Data

Section 2 presents data sources and sectors aggregations. In addition the two types of firm R&D activity analysed in this study are presented. The section also includes a discussion of the firm characteristics potentially related to firms' R&D activity that enter the econometric models in this study.

2.1 Data sources

The data used in this report is taken from the 6th wave of the "Community Innovation Survey" (CIS 2008) carried out in 21 Member States of the European Union and Norway covering the years from 2006 to 2008. The CIS 2008 is the most recent available at the time of preparing this report. This study builds on the original, non-anonymized microdata available through the Eurostat SAFE centre. The CIS data forms a structurally representative picture of general firms' characteristics such as size measured by employment, type of economic sector in which the firms mainly operates, country of origin and geographical markets in which the firm sell goods and services. The CIS questionnaire is structured such that a firm, after having answered questions about general firm characteristics, is asked if it during the year 2006-2008 was involved in finalised, on-going or abandoned product or process innovation activities. If the firm answers yes, it is considered an innovative firm and is asked to provide further information about the firms' R&D and innovative activities and their collaboration and cooperation with other private and public institutions. Box 1 describes the CIS sampling procedure. Detailed information about the CIS data is provided in Appendix 7.1 and 7.2.

The analysis in this report is limited to those 16 EU countries for which data on firms' R&D engagement, firms' R&D expenditure and the chosen set of firm characteristics were available. The study covers the following countries: Bulgaria, Czech Republic, Germany, Estonia, Spain, France, Hungary, Italy, Lithuania, Luxembourg, Latvia, Netherlands, Portugal, Romania, Slovenia and Slovakia.

Hence, the analysis does not include Cyprus, Finland, Ireland, Malta, Sweden, Austria, Belgium, Denmark, Greece, Poland, and the UK.

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6 The CIS 2010 is to become available in late 2013.
8 The European Commission defines firms' size according to employment (headcount) or turnover. This study uses the employment definition due to two reasons. Firstly, employment is a less volatile measure of a firm's size than its turnover, which can change rapidly from year to year as exemplified during the recent economic crisis. Secondly, possibly derived from the previous point employment is much more frequently used as the denominator for calculation of R&D intensity among the existing literature, hence its use here allows for comparison of the finding with other studies.
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Box 1. CIS 2008 sampling procedure

The target population of the CIS 2008 is the total population of enterprises in NACE Rev. 2 sections A to M. These sections include most market activities. The survey excludes NACE Rev. 2 industries from sections O to U consisting of public administration, education, health and social work, arts, entertainment and recreation; other service activities (professional organisations and personal services), households and extraterritorial bodies. The cut off point for inclusion in the target population was the population of enterprises with more than 10 employees in any of the specified sectors. The observation period covered by the survey was 2006-2008 inclusive, i.e. the three-year period from the beginning of 2006 to the end of 2008. The reference period for most indicators was 2006 to 2008. The indicators on innovation expenditures were based on the calendar year 2008. Additionally, information concerning the turnover and employment of enterprises were requested for two years: 2006 and 2008.

The sampling frame was in general the business register with as good quality as possible, containing basic information such as names, addresses, NACE-sector, size and region of all enterprises in the target population. Innovation data was collected both through census or sample surveys. In most countries, resource limitations and response burden ruled out a survey of the entire population (census). The CIS 2008 was often based on mail surveys.

In general, the activity classification (NACE) and the size class of the enterprise in accordance to the number of employees were used for stratification of the sample. The size-classes were at least the following 3 classes: 10-49 employees (small), 50-249 employees (medium-sized) and 250+ employees (large). A more detailed size-band was used in some countries. Stratification by NACE was often on 2-digit level (division). The sample selection was often done according to random sampling. The sample was carried out in order to achieve a certain level of precision with regards to the following indicators: i) the percentage of innovators, ii) the share of new or improved products in total turnover and iii) total turnover per employee.

Source: Eurostat

2.2 Sector aggregations

The uniqueness of the investigation brought by this report relates to its focus on firms from the ICT sector. In order to conduct such analysis, the OECD definition of the ICT sector is followed and, all other, non-ICT firms are allocated into other appropriate sector aggregations. In addition, the analysis covers R&D activity within the ICT sector, by examining separately the R&D activity of films’ in the ICT Manufacturing and ICT Services sub-sectors.

The ICT sector is defined here according to the OECD\(^9\) guidelines, and all other firms are allocated to industrial groups according to an aggregation proposed by Eurostat\(^10\). The Eurostat aggregation of industrial builds on technological and knowledge intensity which is consistent with the specificities adopted in the construct of the ICT sector, and hence allow for a comparison of results between the different groups. In effect, the data is aggregated in to the following four industrial groupings:

- ICT (ICT),
- Other High Technology (oHT),
- Low Technology (LWT),
- Other Services (oSER)

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Table 1 provides an overview of industries included in the ICT sector according to the OECD guidelines. Table 2 contains a description of the industrial groupings used for the analysis. The technical details on the sector composition of each of the four groups are provided in the Appendix.

Table 1: Classification of the ICT sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Description</th>
<th>NACE rev.2 classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT</td>
<td>Information and Communication Technologies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.1 Manufacture of electronic components and boards</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.2 Manufacture of computers and peripheral equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.3 Manufacture of communication equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.4 Manufacture of consumer electronics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.8 Manufacture of magnetic and optical media</td>
<td></td>
</tr>
<tr>
<td></td>
<td>46.5 Wholesale of information and communication equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>58.2 Software publishing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>61 Telecommunications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62.01 Computer programming activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62.02 Computer consultancy activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62.09 Other information technology and computer service activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>63.1 Data processing, hosting and related activities; web portals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>95.1 Repair of computers and communication equipment</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Classification of sectors and industries for the analysis.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Sector / Industrial group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT</td>
<td>Information and Communication Technologies</td>
<td>The ICT sector combines all the firms from the ICT sub-sectors. The ICT sub-sectors are identified according to the OECD ICT sectors definition, and cover the manufacturing of equipment related to electronics, computers and communication technology. It also includes software publishing, telecommunication services and other services and activities provided by and related to the computer and communication activities. Note that inclusion of the wholesale of ICT equipment in this sector, in line with the OECD definition, is based on the rationale that organisations manufacturing ICTs in some OECD countries are often distributors of ICTs in other OECD countries.</td>
</tr>
<tr>
<td>oHT</td>
<td>Other High Technology</td>
<td>The other High Technology sector is defined as being involved in or making use of highly advanced technological development or devices. It is the grouping together of manufacturing industries, according to their technological intensity (R&amp;D spending/value added), using the statistical classification of economic activities in the European Community (NACE). This sector consist of firms from high-tech sub-sectors as defined by Eurostat without, however, the ICT manufacturing firms as defined by OECD. In effect the relevant sub-sectors covered here include manufacturing of chemical products, pharmaceuticals, weapons, advanced machinery and equipment, transport equipment and medical instruments.</td>
</tr>
<tr>
<td>LWT</td>
<td>Low Technology</td>
<td>The Low Technology sector includes all the manufacturing firms which were not included in the ICT manufacturing or in high-technology sectors. The sub-sectors covered here include mostly products which manufacturing does not require use of highly advanced technology, such as food, textiles, wood, printing, petroleum, plastics, basic metals, ships and furniture.</td>
</tr>
<tr>
<td>oSER</td>
<td>Other Services</td>
<td>The other Services sector covers all the service sub-sectors without the ICT service firms which were included in the ICT sector. The broad coverage of this sector is: wholesale and retail, repairs, transportation, accommodation, financial and insurance activities, real estate, administrative activities including public administration, education, health, entertainment and art.</td>
</tr>
</tbody>
</table>

2.3 Firms' R&D activity

This report focuses on two aspects of R&D activity, which are termed **R&D engagement** and **R&D expenditure**. The difference between **R&D engagement** and **R&D expenditure** should be noted for clarity of discussion. A firm is considered as **engaged** into R&D if it undertakes on a continuous basis in-house ‘creative work to increase the stock of knowledge for developing new and improved products and processes’. The **R&D expenditure**, in turn, is an estimated amount of a...

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11 The CIS 2008 questionnaire allows firms to choose between ‘continuous’ and ‘occasional’ R&D activities.  
12 Quoted from the CIS 2008 questionnaire
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The firm’s level of in-house expenditure for R&D activities. Note that having recorded a positive R&D expenditure for a firm does not automatically imply the firm being R&D engaged, as the level of R&D expenditure could be of ‘occasional’ type. To compensate for the variations in R&D expenditure due to company size, our measure of R&D expenditure is expressed as a ratio of R&D expenditures (in thousands of Euros) to employment, R&D expenditure per employee.\(^{13}\)

Table 3 shows the two aspects of R&D activity within the sample of firms analysed in this study. Column 1 shows the share of companies engaged into R&D within the total population of firms as well as within each industry group constructed from the sample. Almost 20% of the firms in the sample reported to be engaged in continuous in-house R&D activity. Large differences in firms R&D engagement can be observed across sectors. The highest degree of R&D engagement can be observed within the other High Tech sector and the ICT sector. This comes as no surprise given these two sectors high technological intensity. Among firms in the other High Tech sector 32% of the firms reported to be engaged in R&D activity while 31% of firms in the ICT sector are engaged in R&D. A lower level of R&D engagement is found in the Low Tech sector where 11% of the firms the reported to be engaged in R&D. The lowest level of R&D engagement is observed amongst firms in the other Services sector with about 5% of the firms engaged in R&D.

<table>
<thead>
<tr>
<th>R&amp;D engagement (pct.)</th>
<th>R&amp;D expenditure per employee (Thousand Euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Sectors</td>
<td></td>
</tr>
<tr>
<td>19.6</td>
<td>6.9</td>
</tr>
<tr>
<td>ICT</td>
<td>31.0</td>
</tr>
<tr>
<td>51.1</td>
<td></td>
</tr>
<tr>
<td>Other High Tech</td>
<td>32.0</td>
</tr>
<tr>
<td>38.4</td>
<td></td>
</tr>
<tr>
<td>Low Tech</td>
<td>10.8</td>
</tr>
<tr>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Other Services</td>
<td>5.4</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>


Column 2 shows the geometric mean of R&D expenditure per employee within the total population of firms and within each industry group\(^{14}\). Please note that only firms that reported R&D expenditures are included in the sample. In 2008 the firms in the sample were spending on average almost seven thousand Euro per employee on in-house R&D activities. The highest average expenditures per employee could be found in the ICT sector (€51,100), followed by firms in the other High Tech sector (€38,400). A notable lower amount per employee was spent on average by firms in the Low tech sector (€3,100) and by firms in the other Services sector (€1,200).

\(^{13}\) The alternative would be to express the R&D expenditure as R&D intensity, which is the ratio of R&D expenditure to the value of sales. This measure, however, is sensitive to firms’ turnover value which is more volatile than number of employees. This applies particularly to the year 2008 when the crisis has significantly impacted on high-tech companies turnover (see, for example “The 2011 Report on R&D in ICT in the European Union” for overview), therefore the number of employees is used here as a more stable measure of company’s size than its sales.

\(^{14}\) Observing firms average expenditures one has to keep in mind that the reported means of the firms’ expenditures per employee are sensitive to the skewness of the distribution and to the sample size. Hence, very large R&D expenditure per employee by a small number of firms (positively skewed distribution) would affect the means, especially if the sample size is small. However, keeping the examination of average firm expenditure at the aggregated industry groupings ensures sufficiently large samples to make these concerns less of a problem.
Large differences in firms’ R&D activity exist across countries in the sample. To illustrate these differences one may examine firms’ R&D engagement across countries in the sample. Figure 1 shows the share of companies engaged into R&D within the total population of companies in each country. The percentage of companies which are engaged into R&D differs largely between countries. The country with the highest share of R&D engaged firms is Germany (over 35%). Another three countries (Netherlands, Slovenia and France) have above 30% of their firms engaged into R&D activity. Remaining countries have shares below 20%, with the exception of the Czech Republic (22%). There are six countries with shares below 10% (Italy, Spain, Latvia, Hungary, Lithuania and Bulgaria).

**Figure 1: Percentage of companies engaged in R&D activity by country, all sectors**

![Figure 1: Percentage of companies engaged in R&D activity by country, all sectors](source)

Figure 2 shows the share of the R&D engaged firms of each industry group in each country. The upper left graph focuses on firms’ R&D engagement in the ICT sector. It can be seen that about 60% of German ICT companies are engaged into R&D activity. In four other countries these shares are at least 50% (France, Slovakia, Slovenia and Portugal). At the other end of this ranking are ICT firms in Lithuania, Latvia, Hungary and Bulgaria (all below 20%). The upper right graph presents the R&D engagement of Other High Tech firms. For easier reading, the countries are ranked according to the ICT sectors graph. In the Netherlands, the share of companies within the other High Tech sector that are engaged into R&D activity reaches 65%. For Germany the share is above 60%. R&D engagement of firms in the Other High Tech sector is lowest in Lithuania, Latvia, Hungary and Bulgaria (also here all below 20%). Looking at the lower two graphs (Low Tech and non-ICT Services), one may note that, the share of R&D engaged firms in Low Tech and other Services are rarely above 20%. In these two sectors the shares of companies performing R&D activity are the highest in the Netherlands, France, Germany and Slovenia.
This section presented the two aspects of R&D activity analysed in this study and illustrated differences in firms’ R&D activity across sectors and countries. In the next section we identify characteristics of firms that may potentially account for such differences in firms’ R&D activity.

2.4 Firm characteristics associated with R&D activity

This section identifies firm characteristics which may be of relevance for firms’ R&D activity. The aim is to identify variables in the CIS questionnaire and, subsequently, in the CIS dataset which may potentially influence firms’ R&D activity and hence, should enter the econometric analysis of firms’ R&D behaviour. Note that, the overall notion of this study builds upon the decisions that firms make with respect to R&D. Therefore, the analysis is particularly concerned with factors upon which a firm has a decisive power such as cooperation with other firms or using particular sources of information. However, this study also includes given firms’ characteristics such as size, country where it operates or sector allocation. Those given characteristics are important additional information which should be taken into account in the analysis of firms’ R&D activity.

Public funding

Some firms receive public funding to cover part of their R&D expenditure. Public funding may be given to a firm with the purpose of initiating new R&D projects or to expand existing ones, and hence as a remit to increase the firm’s own R&D spending. However, government funding may also be given to firms with the purpose to increase inter-firm R&D co-operation and allocative efficiency and thereby to avoid duplicated expenditures on R&D. This type of government funding could

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15 For more details on the identified variables see the Appendix or the CIS2008 questionnaire. Available from for example, : [http://innovacion.ricyt.org/files/CIS%202006%202008.pdf](http://innovacion.ricyt.org/files/CIS%202006%202008.pdf)
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reduce firms R&D expenditure. In addition, government funding may lead to crowding-out by replacing R&D expenditure that previously was undertaken by the firm. To analyse the role of government funding in firms’ R&D decisions we constructed a set of variables indicating whether the enterprise received innovation related funding from government, with three possible sources of funding: local, national, and EU. Please note that a firm may receive public funding from more than one source. The share of innovative firms in the sample that received local government funding is 9%, while the share of innovative firms receiving national government funding is 11%. Funding from the EU is received by 4% of the innovative firms, while 82% of the innovative firms, the largest majority, reported to have received no public funding.

Geographical markets and competition

The larger the market, the higher the potential competition a firm faces, which can have implications for its efficiency, innovativeness and, consequently, R&D effort. The CIS identifies predominant geographical markets in which a firm sells its good and/or services, with the options being: (i) local / regional, (ii) national, (iii) other EU / EFTA / EU candidates\textsuperscript{16}, and (iv) all other markets. The sequence i to iv increases the market reach and leads to higher internationalisation of the target market, which in turn, one could assume, leads to a greater degree of competition. The variable is coded in the econometric model as a single binary variable\textsuperscript{17}, ‘exporter’ which takes values of 0 if the firm sells within its national markets (i and ii) or 1 if the firm exports (iii and iv).

The share of firms in the sample that reported to export goods or service is 24%.

Cooperation

R&D is, frequently, a network activity. The existence of cooperative innovation arrangements may therefore influence a firm’s R&D decision. The innovation cooperation dummy variable indicates if the enterprise had any relevant cooperative arrangements with other enterprises or institutions, exclusive of pure contracting out with no active cooperation; the cooperation does not need to be commercially beneficial. The share of innovative firms in the sample that indicated to be involved in cooperative innovative arrangements is 32%.

Enterprise group

Organizational structure may also influence a firms R&D decisions. Firms belonging to a larger enterprise group may have better access to information or organizational resources that may influence their R&D activity. To examine the importance of organizational structure a dummy variable was constructed that indicates whether the firm is part of an enterprise group (1) or is independent (0). The share of firms in the sample belonging to an enterprise group is 31%.

Sources of information

In their R&D activity firms may obtain information relevant to their innovative activity from a number of different sources. Possible sources from which enterprises could obtain relevant information include: within the enterprise, from suppliers, clients, competitors, consultants, universities, governments, conferences, scientific journals and technical publications, and professional and industry associations. In this study the sources of information are grouped into four categories: internal sources (within the enterprise), market sources (suppliers, clients, competitors and consultants), institutional sources (universities and governments), and other sources (conferences, scientific journals and technical publications, and professional and industry association).

\textsuperscript{16} The following EU countries, EFTA, or EU candidate countries are included here: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Ireland, Latvia, Liechtenstein, Lithuania, Luxembourg, Macedonia, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Slovakia, Switzerland, Turkey, Spain, Sweden and the United Kingdom.

\textsuperscript{17} In statistics, a binary variable or a categorical variable (also known as a dummy variable) is one that takes the value 0 or 1 to indicate the absence or presence of some categorical effect. Dummy variables are used as devices to sort data into mutually exclusive categories (such as male/female, smoker/non-smoker, etc.).
associations). The share of innovative firms that reported the use of *internal sources, market sources, institutional sources* and *other sources* is respectively 87%, 89%, 41% and 72%.

**Firm-size dummy**

In addition to the firm characteristics identified as potentially related to firms’ R&D activity we include a set of firm-size dummies in the estimations. The firm size dummies may be correlated with other factors which may be related to firms R&D activity. For example large firms may have better access to private funding for R&D project or benefit from organisational economies of scale. The firm-size dummies capture these effects that may potentially be related to firms’ R&D activity.

**Sector dummy**

As noted in the previous section firms’ R&D activity seems potentially related to the sector in which the firm operates. Such industry specific differences may for example be due to production techniques or sector specific regulation that influence firms R&D decisions. A sector dummy covering the sectors described in section 2.2 is included in the econometric analysis to capture sector specific effects that may potentially be related to firms’ R&D activity.

**Country dummy**

A set of country dummies are included to capture country specific effects that may be related to firms R&D activity. These may for example be country specific regulation, country variations in access to private funding or country variations in firms’ access to a workforce with the relevant skills for R&D.
3. **Econometric models**

This section presents the inferential econometric models used to derive generalised information about the firms' R&D activity. The analysis of the firms' R&D engagement decisions and their in-house R&D expenditure levels, are addressed with two separate models. The analysis of firms' engagement into continuous R&D is undertaken with a Probit model. The Probit model allows for an analysis of how certain characteristics of firms impact on their probability to engage into R&D. When using the Probit model in the analysis of firms' R&D engagement one has to note the difference between occasional and continuous engagement into R&D. Continuous R&D engagement is used as the dependent variable in the Probit model, whereas some of the explanatory variables in that model may be related to occasional R&D activities undertaken by firms, such as seeking relevant information from governments or cooperating with clients. Explanatory variables related to occasional R&D activities may not perfectly predict continuous R&D engagement. However, they can still be used as covariates in the Probit model. The Probit model is used in two separate estimations. Firstly, the model is fitted to the sample of firms from all sectors (including ICT sector firms). Secondly, the Probit model is fitted to the sample of ICT firms. Fitting the model to these two samples allow us to examine whether the effects of firm characteristics on firms' R&D engagement differs between the ICT sector and the broad economy.

A second model is employed to analyse firms R&D expenditure levels. Here a set of firms' characteristics are correlated with their in-house R&D expenditure per employee by using the Tobit model that is best suited for estimations with dependent variable that is continuous over its positive values but is zero for a nontrivial fraction of the sample. The dependent variable in the R&D expenditure (Tobit) model is (log of) R&D expenditure per employee. Hence, the dependent variable is by construct defined such that expenditure levels are comparable across firms of different size. Expenditure levels per employee may still vary with firm-size and failing to control for firm-size differences could influence our estimates of R&D expenditure levels across firms. To control for firm-size differences in R&D expenditure per employee the set of firm-size dummies are included in the Tobit model. The Tobit model is also estimated twice. First, the model is fitted to the sample of firms from all sectors (including ICT sector firms) and second, the Tobit model is fitted to the sample of ICT firms.

Table 4 below provides a schematic guide to the scope of the two models and the main questions they address.
Table 4: The main questions addressed by the different variables in the models

<table>
<thead>
<tr>
<th>Model description</th>
<th>Decision to engage into R&amp;D</th>
<th>Decision on amount of resources dedicated to R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column number</td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td><strong>Scope Variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exporter, Cooperation, Enterprise group,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public funding, Sources of information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>**Exporter, Cooperation, Enterprise group,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public funding, Sources of information</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Size of the firm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sectors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Countries</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- All industries
- ICT industry
- All industries
- ICT industry

- How do firm characteristics affect the probability to engage in R&D?
- How do firm characteristics affect the probability to engage in R&D?
- What is the impact of firm characteristics on the firms’ R&D expenditure levels?
- What is the impact of firm characteristics on the ICT firms’ R&D expenditure levels?

- How does the decision to engage in R&D differ among firms of different sizes?
- How does the decision to engage in R&D differ among ICT firms of different sizes?
- How do R&D expenditure levels per employee vary with firm-size?
- How do R&D expenditure levels per employee among ICT firms vary with firm-size?

- How likely are the ICT manufacturing firms to engage in R&D compared to ICT service firms?
- How different is the R&D expenditure level per employee by firms in different countries?
- How different is the R&D expenditure level per employee by ICT firms in different countries?
Investigation of Firms' Decisions on R&D Investment

4. Results

Table 5 provides an overview of the results from the Probit model and the Tobit model estimations. The structure of Table 5 follows the structure of Table 4. Note that the estimates from the two models are to be interpreted relative to a reference group. The necessity for a reference group is a technical requirement for the types of econometric models used here\(^\text{18}\), and the choice of the reference group is, in theory, arbitrary. The reference group chosen here is a small firm from the Low Tech sector in Hungary which receives no public funding, chosen such that the overall results are estimated within a sensible range. For the variables Exporter, Cooperation and Enterprise Group the natural references are non-Exporter, no-Cooperation and not-part-of-Enterprise Group, respectively. For the category Sources of Information the reference is not using any Sources of Information.\(^\text{19}\)

The estimation results in Table 5 are reported with three commonly used levels of statistical significance (10%, 5% and 1%). The star symbol (*) next to the coefficient estimate indicate the statistical significance level, where more stars indicate a higher confidence level. Hence, a coefficient estimate marked with the symbol (****) indicates that the coefficient is found to be statistically significant at a 99% confidence level. Results which are found to be of statistical significance with less than 90% confidence level are rejected and have no stars associated.

The Probit model is used to analyse firms’ decision to engage into R&D. Column 1 and 2 in Table 5 present estimates of the marginal effects from the Probit model. The estimation results on the entire sample of firms covering all sectors are shown in column 1, while the estimation results on the subsample of ICT firms are shown in column 2. The estimates of the marginal effects can be interpreted as changes in the probability to engage into R&D between a reference group and the group considered. For example, the most upper value in column 1 of Table 5 equals 0.119 meaning that an exporting firm is 11.9% more likely to engage into R&D than non-exporting firms in the reference group.

The Tobit model is used to examine the relation between firm characteristics and firms’ R&D expenditure levels per employee. Columns 3 and 4 present estimates of the marginal effects from the Tobit model for the sample of firms in all sectors and for the sample of ICT firms respectively. Because the dependent variable for the Tobit model estimations is the logarithm of R&D expenditure per employee, the estimates can be interpreted as the percentage change in the expenditure due to difference between the reference group and the variable in question. For example, in the all-industry sample model (column 3) the ICT sector is associated with a statistically significant estimate of 2.849, meaning that an average firm in the ICT sector has a R&D expenditure level per employee that is 284.9% greater than its counterpart firm in the Low Technology sector (the reference); note that the magnitude of this effect is the average for all countries in the sample.

\(^{18}\) Since all of the explanatory variables used are binary choice (0,1) variables, one category of each variable has to be omitted in order to avoid collinearity, and, in effect, the omitted group serves as the reference category.

\(^{19}\) There are firms in the panel which report no use of any sources of information, hence this is used as an omitted base group to avoid collinearity.
Table 5: Estimates of marginal effects on firms' R&D engagement and R&D expenditure levels per employee.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>R&amp;D engagement (binary response)</th>
<th>R&amp;D expenditure level (R&amp;D expenditure/employee)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Column number</td>
<td>(1)</td>
</tr>
<tr>
<td>Sample</td>
<td>All sectors</td>
<td>ICT industry</td>
</tr>
<tr>
<td>Exporter</td>
<td></td>
<td>0.119***</td>
</tr>
<tr>
<td>Cooperation</td>
<td></td>
<td>0.096***</td>
</tr>
<tr>
<td>Enterprise group</td>
<td></td>
<td>0.026***</td>
</tr>
<tr>
<td>Public funding</td>
<td>Local</td>
<td>0.026**</td>
</tr>
<tr>
<td></td>
<td>National</td>
<td>0.189***</td>
</tr>
<tr>
<td></td>
<td>EU</td>
<td>0.041**</td>
</tr>
<tr>
<td>Sources of information</td>
<td>Internal</td>
<td>0.147***</td>
</tr>
<tr>
<td></td>
<td>Market</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>Institutiona</td>
<td>0.080***</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>0.064***</td>
</tr>
<tr>
<td>Country</td>
<td>HU</td>
<td>Reference</td>
</tr>
<tr>
<td></td>
<td>BG</td>
<td>-0.146***</td>
</tr>
<tr>
<td></td>
<td>CZ</td>
<td>0.101***</td>
</tr>
<tr>
<td></td>
<td>DE</td>
<td>0.203***</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>0.142***</td>
</tr>
<tr>
<td></td>
<td>FR</td>
<td>0.219***</td>
</tr>
<tr>
<td></td>
<td>IT</td>
<td>0.154***</td>
</tr>
<tr>
<td></td>
<td>LT</td>
<td>0.083*</td>
</tr>
<tr>
<td></td>
<td>LU</td>
<td>0.171***</td>
</tr>
<tr>
<td></td>
<td>PT</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td>RO</td>
<td>0.053**</td>
</tr>
<tr>
<td></td>
<td>SI</td>
<td>0.082***</td>
</tr>
<tr>
<td></td>
<td>EE</td>
<td>0.037</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>-0.109***</td>
</tr>
<tr>
<td></td>
<td>NL</td>
<td>0.179***</td>
</tr>
<tr>
<td></td>
<td>SK</td>
<td>0.049</td>
</tr>
<tr>
<td>Size</td>
<td>Small</td>
<td>Reference</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.062***</td>
</tr>
<tr>
<td></td>
<td>Large</td>
<td>0.114***</td>
</tr>
<tr>
<td>Sectors</td>
<td>LWT</td>
<td>Reference</td>
</tr>
<tr>
<td></td>
<td>ICT</td>
<td>0.170***</td>
</tr>
<tr>
<td></td>
<td>oSER</td>
<td>-0.062***</td>
</tr>
<tr>
<td></td>
<td>oHT</td>
<td>0.141***</td>
</tr>
<tr>
<td></td>
<td>ICTS</td>
<td>Reference</td>
</tr>
<tr>
<td></td>
<td>ICTM</td>
<td>0.096**</td>
</tr>
<tr>
<td>Observations</td>
<td>53486</td>
<td>4907</td>
</tr>
</tbody>
</table>

*significant at 10%, **significant at 5%, *** significant at 1%
The following sections present selected estimation results from Table 5 with the aid of graphs and figures. It is very important to carefully interpret the results, and to avoid the comparison of results from different regressions, as they have various reference groups. The next section looks at the results of the analysis on R&D engagement (Column 1 and 2 in Table 5), followed by a section dedicated to the analysis of firms’ R&D expenditure per employee (Columns 3 and 4).

4.1 Firms’ R&D engagement

Using the Probit model we estimated how various firm characteristics affect the firms’ probability to engage in continuous in-house R&D activity relative to the reference group. Figure 3 show the estimation results for four categories of explanatory variables: public funding source, type of information sources used, firm-size, and a group of organizational and market factors which comprises elements such as being part of an enterprise group, cooperation and being an exporter. The results are discussed in turn below.

Figure 3: Probability to engage into R&D activity with respect to public funding source, organizational and market factors, type of information sources used and firm-size, all industries and the ICT industry.
Public funding sources: The results show a positive relation between public funding and firms' engagement into continuous R&D. Firms which receive funding from governments at national level are associated with 19% greater likelihood to undertake R&D, and firms which receives EU funding have 4% more chances to engage in R&D. Firms receiving local government funding is associated with 3% greater likelihood to engage in R&D. For firms from the ICT sector the likelihood to engage in R&D is 24% greater for firms receiving national government funding, while the reception of EU funding makes a 10% positive difference. No statistically significant relation was found between funding from local government and ICT firms R&D engagement.

Exporter: Firms in the all-sector sample which export goods or services are found to be 12% more likely to undertake R&D than non-exporting firms, while exporting ICT firms is 11% more likely to engage in R&D activities than non-exporters.

Cooperation: Firms which report any kind of innovative cooperation are found to have a higher probability to engage in R&D activity than those which do not. Cooperation is found to increase the probability to engage in R&D by 10% for firms the all-sector sample, as well as for ICT firms.

Enterprise group: Estimates on the all-sectors sample show that firms which are part of an enterprise group correlate with a 3% larger likelihood of doing R&D. ICT firms belonging to an enterprise group are 5% less likely to engage in R&D.

Information sources: Availability of R&D relevant information has statistical significant impact on firms' decision to enter R&D. For the sample covering all sectors, availability of information within the enterprise is associated with 15% increased probability of R&D engagement, followed by an 8% increase due to use of information from institutional sources (governments or universities), and a 6% increase due to other sources of information (conferences, journals, exhibitions, etc.). For firms in the ICT industry, availability of information from internal sources correlates with a 29% higher probability of doing R&D, and the use of information from market sources (suppliers, clients, competitors) relates to a 16% higher probability of R&D engagement. 'Other' types of information sources accounts for a 7% increase in the ICT firms' probability for R&D engagement, while the use of information from institutional sources increase the firms' probability to engage in R&D by 6%.

Firm-size: For the all-sectors model the results indicate that, relative to small firms, medium size firms have 6% higher probability of doing R&D, while the probability for large firms is 11% higher. For ICT firms the results are not statistically significant, indicating that firm-size does not seem to influence the decision to engage in R&D for ICT firms.

Sector: Figure 4 shows the estimated relations between sector and firms R&D engagement. The yellow bars in the figure show the probability of firms in the ICT sector, Other High Tech sector and other Services sector to engage into R&D activity relative to firms from the Low Tech sector. The results indicate that ICT firms are the most likely to enter R&D, the probability being 17% larger than the Low Tech sector firms. The other High Tech sector firms are 14% more likely to go into R&D, while firms from the other Services sector are 6% less likely to begin R&D activities than firms in the Low Tech sector. The blue bar shows the estimate from the subsample of ICT firms. The result indicates that the ICT Manufacturing firms are 10% more likely to engage in R&D than firms in ICT Services sector.
Country: Figure 5 shows the probability to engage into R&D activities for firms in 15 different countries relative to firms in Hungary (the reference group). Results are shown separately for estimates on the all-sectors sample and for the sample of ICT firms. Estimates for the all-industry sample (orange bars) indicate that French firms are most likely to engage into R&D with the probability being 22% larger than that of Hungarian firms. French firms are followed by German, Dutch, Luxembourghian, Italian, and Spanish firms, which are respectively 20%, 18%, 17%, 15% and 14% more likely to do R&D than the Hungarian firms. Firms from the Czech Republic, Lithuania, Slovenia and Romania were also found to be more likely to engage in R&D than Hungarian firms with probabilities ranging from 10% to 5%. Bulgarian and Latvian firms are respectively 15% and 11% less likely to undertake any R&D than the Hungarian firms.

Estimates on the sample of ICT firms show a different pattern in the relation between firms’ R&D engagement and their country of origin. The ICT firms which are most likely to enter R&D activity are those from Slovakia (29% more likely than Hungarian firms), closely followed by firms from France, Spain, Germany, Luxembourg and Czech Republic (firms from those countries are from 18% to 25%, more likely to engage in R&D than Hungarian firms). Firms in Luxembourg and Slovenia are also found to be more likely to engage in R&D than their Hungarian counterpart, respectively 18% and 16% more likely. Bulgarian and Latvian ICT firms are 36% and 22% less likely to enter into R&D than firms from Hungary. Results for ICT firms in the remaining countries are not statistically significant.
**Figure 5: Probability to engage into R&D activity across countries relative to Hungary, for all industries and the ICT industry**

4.2 Firms' R&D expenditures

The Tobit model was used to estimate correlations between firms' characteristics and their R&D expenditure levels. The R&D expenditure level is expressed here as the logarithm of in-house R&D expenditure per employee, hence the estimates from the Tobit model are interpreted as percentage change resulting from changes in the explanatory variable.

Figure 6 shows the estimation results for four categories of explanatory variables: government funding, sources of information, firm-size, and a group of organizational and market factors.

*Public funding:* Results show that firms R&D expenditure levels are correlated with funding from national and local governments. The results from the all-sectors sample show that firms receiving funding from national government spend more than four times more on in-house R&D per employee than firms receiving no funding. ICT firms receiving funding from national government is found to spend more than three times more on R&D per employee. Funding from local governments is found, in the all-sectors sample, to increase the R&D spending per employee by 70% relative to firms receiving no funding. ICT firms receiving local government funding is associated with a doubling of R&D expenditures per employee. No statistical significant difference in in-house R&D expenditure per employee is found for firms receiving EU funding.

*Exporter:* Exporting firms in the all-sector sample have about 200% higher R&D expenditure per employee than the non-exporting firms, whereas being an exporting ICT firm is associated with a 80% increase in R&D expenditure per employee.

*Cooperation:* The estimation results show that Cooperation is found to increase R&D spending per employee by 200% in the all-sector sample and about 150% for the ICT firms.

*Enterprise group:* Membership of an enterprise group comes with a 90% reduction of R&D expenditure per employee for the ICT firms, but does not seem to have any statistically significant impact on the R&D expenditure per employee in the all-sectors sample.
Information sources: The results show a clear relation between firms' use of information sources and their R&D expenditures. The use of internal sources of information is associated with the highest increase in R&D expenditure per employee in both the all-sectors sample and in the subsample of ICT firms, the increase in expenditure per employee being about 450% for both samples. Internal sources of information are associated with a 450% higher R&D. The market sources on information correlate with a 250% larger R&D expenditure for the ICT firms, whereas the increase for firm in the all-sectors sample is about 60%. The use of other information source such as conferences, scientific journals, technical publications, and professional and industry associations is associated with an increase in R&D expenditure per employee of 170% in the all-sector sample and 150% for ICT firms. Firms in the all-sector sample using information from institutional sources (such as universities or governments) are found to have a 150% higher R&D expenditure. No statistically significant relation between institutional information sources and R&D expenditures is found for ICT firms.

Firm size: No clear relation is found between firm-size and firms’ R&D expenditure level per employee. The results from the all-sector sample suggest that, compared to small firms, the medium size firms spend about 40% more on R&D per employed. No statistical significant difference is found between ICT medium sized firms and small ICT firms. Large ICT firms are found to spend 75% less resources on R&D per employee than small ICT firms. No statistically significant
A difference in R&D expenditure level is found between large firms and small firms from the all-sectors sample.

**Sector:** R&D expenditure level across different sectors is pictured in Figure 7. ICT firms have a level of R&D expenditure per employee that is 285% larger than firms from the Low Technology sector, the reference. Firms from the Other High Tech sector spend 260% more on R&D per employee than the Low Tech sector, and firms in the Other Service sector spend 190% less on R&D per employee than Low Tech sector firms. Results for the ICT sub-sectors show that ICT manufacturing firms spend 75% more on R&D per employee than firms in the ICT services sector.

**Figure 7: R&D expenditure per employee across all-industries and the ICT industry**

![Graph showing R&D expenditure per employee across different sectors](image)

**Country:** Country dummies were included in the Tobit models to capture country specific effect on firms R&D expenditure level. Figure 8 below pictures the percentage difference in R&D expenditure per employee for firms in 15 EU countries relative to firms in Hungary for both the all-sectors sample and the subsample of ICT firms. Within the all-sectors sample, the top three countries with firms spending most on R&D per employee are Latvia, France, and Lithuania – their firms dedicate four to seven times as much R&D resources per employee than their Hungarian counterparts. R&D expenditures per employee of firms in the Netherlands, Italy, Germany, the Czech Republic, Slovenian and Spain are about two to three times higher than that of Hungarian firms. In contrast, R&D expenditures per employee by Bulgarian firms are 800% lower than that of Hungarian firms, while R&D expenditures by Estonian firms are 80% lower. Estimates of the remaining country dummies are not statistically significant.
A relation between firms' country of origin and their R&D expenditures is also found for ICT firms. The results for the ICT industry do change the ranking of countries. Latvian ICT firms, again leading, show more than 500% higher in-house R&D expenditure per employee than Hungarian firms, these are followed by ICT firms in France, Spain, Germany and Portugal. Bulgarian firms would dedicate fewer resources into R&D activities to achieve almost 800% lower expenditure per-employee than Hungarian firms. Estimates of the remaining country dummies are not statistically significant.
5. Discussion and conclusions

This report analyses R&D activities among firms grouped in four main economic sectors: ICT, Other High Technology, Other Services and Low Technology. Particular attention and in-depth analysis is given to the firms from the ICT sector. The analysis covers two aspects of the firms’ R&D activity. Firstly, R&D engagement characterising those firms which undertake in-house R&D projects on a continuous basis, and secondly, R&D expenditure measures as the firms’ expenditure levels on in-house R&D projects per employee.

Two different econometric models are used in the analysis of firms’ R&D activity. The Probit model is used to estimate how various firm characteristics affect the firms’ probability to engage in continuous R&D activity. The Tobit model is used to estimate the relation between firms’ characteristics and their R&D expenditure levels. Both econometric models are used in two separate estimations. Firstly, the models are fitted to the sample of firms from all sectors (including ICT sector firms). Secondly, the models are fitted to a subsample of ICT firms. Fitting the models to these two samples makes it possible to examine whether the effects of firm characteristics on firms’ R&D engagement differ between the ICT sector and the broad economy.

The results provide valuable insight for the formulation of a macroeconomic model containing ICT R&D which will be applied to the analysis of ICT R&D funding strategies under the PREDICT 2 project. The results from this study provide estimates on the transmission from public funding to firms’ R&D activity, provide further insight on the dissemination of knowledge across firms and its effect on firms R&D activity, and illustrate the heterogeneity in R&D activity across industrial sectors and countries within the EU.

The results show that public funding is positively related with firms’ R&D activity and that this relation differs with funding sources. Funding from national government is found to have the strongest relation to firms’ engagement in R&D and to their R&D expenditures per employee. The positive correlation between national government funding and firms R&D activity is found for firms’ in the all-sectors sample as well as in the subsample of ICT firms. The results also reveal a positive relation between local government funding and firms R&D activity with the exception of ICT firms’ R&D engagement were no statistically significant relations is found. Funding from the EU is found to be positively related to firms’ R&D engagement. However, no statistically significant relation is found between EU funding and firms expenditures on in-house R&D per employee. These results deliver two important insights for a CGE model based analysis of ICT funding policies. Firstly, the results suggest that public funding and private ICT investments should be considered as complements, i.e. public funding tends to increase firms R&D activity rather than replace existing private R&D initiatives and crowd out private R&D expenditures. Secondly, differences in the relation between public funding and firms R&D activity indicate that special attention should be made to the modelling of linkages between various public funding sources and private sector R&D expenditure levels. The results stress the importance of carrying out sensitivity analysis of how ICT firms’ R&D expenditure responds to public funding and its implications for the outcome of public ICT R&D funding policy.

The results illustrate how national and international dissemination of knowledge through firms’ cooperation with other enterprises and through international trade plays an important role for firms’ R&D activity. Cooperation with other enterprises, international trade and exchange of information with institutional and market cooperation partners were all found to be positive related to firms R&D activity. A CGE model of R&D activity should thus include the dissemination of knowledge arising both from national cooperation and exchange of ideas as well as from the diffusion of knowledge internationally through cooperation and trade.

The results also suggest that firms’ R&D activity differ across the EU member states. For example, estimates suggest that in-house R&D expenditures per employee for ICT firms based in Latvia,
France, Spain, Germany and Portugal is higher than for firms based in other member states after controlling for other firm characteristics. The sector in which the firm operates also largely influences the firm's R&D activity. ICT firms is found to be most likely to engage in R&D and to undertake the highest in-house R&D expenditure per employee, followed by firms from the other High Tech sector. Firms in the other Service sector are the least likely to engage in R&D and have the lowest expenditure per employee. The results from the sample of ICT firms show that the ICT Manufacturing firms are more likely to engage in R&D than the ICT Services firms, and that they also undertake the highest expenditure per employee. Such heterogeneity in firms R&D activity across sectors and countries should be accommodated by the GCE model.

As always, caution should be made when interpreting the results. Note that while the results suggest that say national government funding correlates with the firms' R&D activity, they do not imply causality between national government funding and R&D activity. Similarly, the higher estimated coefficients on the relation between firms' R&D activity and national government funding than the estimated coefficients for other public funding sources should not lead one with certainty to conclude that national government funding leads to higher R&D activity amongst firms than other types of public funding. It is also possible that national government funding to a larger extend is given to firms that happen to have higher R&D activity.

One should also note that the estimates merely show firms' R&D activity against the existence of various firm characteristics. For example, the CIS survey does not contain information about the amount of public funding provided but merely if funding is received by the firm and from which source (the questionnaire provides simple yes/no answers). Systematic differences in the amounts given by the various funding bodies could influence the results. If the amounts of funding provided to the firms differ largely across funding sources, then one could expect that the outcome of the funding policies would also differ across funding sources. For example if national funding generally imply higher amount of funding to the firms than EU funding, then the existence of national funding may have a higher impact on firms R&D expenditure than the existence of EU funding. Likewise, the CIS survey does not contain information on the amount of export or the degree of cooperation that a firm undertakes, systematic differences could therefore influence the results.

In addition the relation between funding sources and firms' R&D expenditure may not per se tell us about the efficiency of the funding policies adopted by the different policy units. Differences in firms’ R&D activity as a result of funding from different sources may be due to differences in the policy objectives of the two funding bodies. For example, if national funding policies to a higher extent aim at expanding R&D expenditure by domestic firms, while EU funding policies also aim at increasing R&D cooperation between firms at the EU level and improving allocations of R&D funds (thereby avoiding duplicated R&D expenditures), then national funding policies would be associated with a higher R&D expenditure per employee for the firms receiving the funds. However, both set of funding policies could still be successful in reaching their objectives.

In spite of its shortcomings this study provides valuable insights that will be utilized in the formulation of a macroeconomic model containing ICT R&D and applied to the analysis of ICT R&D funding strategies.
6. References


EUROSTAT. (2009). ‘High-technology’ and ‘knowledge based services’ aggregations based on NACE Rev. 2.


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7. Appendix

7.1 Covariates

Sector aggregation

Specificity and nature of R&D decision and innovation dynamics varies across sectors and industries, and across time and geography, therefore controlling for the sector-specific related effects is necessary. In accordance with the OECD definition\(^\text{20}\) of the ICT sector, and with the Eurostat guidelines\(^\text{21}\) for aggregating industries with respect to their technological intensity (for manufacturing sectors) and knowledge intensity (for service sectors), the following aggregation was made (see Table for overview and Table 2 for details) and the set of indicator variables was created:

a. ICT (ICT)

b. Other High Technology (oHT)

c. Low Technology (LT)

d. Other Services (oSER)

Table 2: Classification of sectors and industries for the analysis

<table>
<thead>
<tr>
<th>Sector</th>
<th>Description</th>
<th>NACE rev.2 classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT</td>
<td>Information and Communication Technologies</td>
<td>26.1 Manufacture of electronic components and boards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26.2 Manufacture of computers and peripheral equipment</td>
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<tr>
<td></td>
<td></td>
<td>26.3 Manufacture of communication equipment</td>
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<td></td>
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<td>26.4 Manufacture of consumer electronics</td>
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<td></td>
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<td>26.8 Manufacture of magnetic and optical media</td>
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<td></td>
<td></td>
<td>46.5 Wholesale of information and communication equipment</td>
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<tr>
<td></td>
<td></td>
<td>58.2 Software publishing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61 Telecommunications</td>
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<tr>
<td></td>
<td></td>
<td>62.01 Computer programming activities</td>
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<tr>
<td></td>
<td></td>
<td>62.02 Computer consultancy activities</td>
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<tr>
<td></td>
<td></td>
<td>62.09 Other information technology and computer service activities</td>
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<tr>
<td></td>
<td></td>
<td>63.1 Data processing, hosting and related activities; web portals</td>
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<tr>
<td></td>
<td></td>
<td>95.1 Repair of computers and communication equipment</td>
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<tr>
<td>oHT</td>
<td>Other High Technology</td>
<td>20 Manufacture of chemicals and chemical products</td>
</tr>
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<td></td>
<td></td>
<td>21 Manufacture of basic pharmaceutical products and pharmaceutical prep.</td>
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<td></td>
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<td>25.4 Manufacture of weapons and ammunition</td>
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<td></td>
<td></td>
<td>26 Manufacture of computer, electronic and optical products</td>
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<tr>
<td></td>
<td></td>
<td>ICT subsectors 26.1, 26.2, 26.3 and 26.4 are excluded here</td>
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<tr>
<td></td>
<td></td>
<td>27 Manufacture of electrical equipment</td>
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<td></td>
<td></td>
<td>28 Manufacture of machinery and equipment n.e.c.</td>
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<td></td>
<td></td>
<td>29 Manufacture of motor vehicles, trailers and semi-trailers</td>
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<td></td>
<td></td>
<td>30 Manufacture of other transport equipment - excluding 30.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32.5 Manufacture of medical and dental instruments and supplies</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>LT</th>
<th>Low technology</th>
<th>G</th>
<th>Wholesale and retail trade; repair of motor vehicles and motorcycles</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>H</td>
<td>Transportation and storage</td>
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<td>I</td>
<td>Accommodation and food service activities</td>
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<td>J</td>
<td>Information and communication</td>
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<td>K</td>
<td>Financial and insurance activities</td>
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<td>L</td>
<td>Real estate activities</td>
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<td></td>
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<td>M</td>
<td>Professional, scientific and technical activities</td>
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<td>N</td>
<td>Administrative and support service activities</td>
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<td>O</td>
<td>Public administration and defence; compulsory social security</td>
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<td>P</td>
<td>Education</td>
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<td></td>
<td>Q</td>
<td>Human health and social work activities</td>
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<td></td>
<td></td>
<td>R</td>
<td>Arts, entertainment and recreation</td>
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<td></td>
<td></td>
<td>S</td>
<td>Other service activities</td>
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<td></td>
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<td>T</td>
<td>Activities of households</td>
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<td></td>
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<td>U</td>
<td>Activities of extraterritorial organisations and bodies</td>
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<td></td>
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<td></td>
<td><em>ICT subsector 46.5 is excluded here</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>ICT subsectors 58.2, 61, 62.01, 62.02, 62.09 and 63.1 are excluded here</em></td>
</tr>
</tbody>
</table>

| oSER | Other Services | 10 - 17 | Manufacture of food products, beverages, tobacco products, textiles, wearing apparel, leather and related products, wood and of products of wood, paper and paper products |
|      |               | 18     | Printing and reproduction of recorded media                      |
|      |               | 19     | Manufacture of coke and refined petroleum products               |
|      |               | 22 - 24| Manufacture of rubber and plastic products, Manufacture of other non-metallic mineral products, Manufacture of basic metals |
|      |               | 25     | Manufacture of fabricated metal products, except machinery and equipment - excluding 25.4 |
|      |               | 30.1   | Building of ships and boats                                      |
|      |               | 31     | Manufacture of furniture                                         |
|      |               | 32     | Other manufacturing - excluding 32.5                             |
|      |               | 33     | Repair and installation of machinery and equipment               |

Note: For Finland and the Netherlands, data is available only at 2-digit NACE classification level. Therefore, a broader definition of these four sectors has to be applied.

**Firm size**

Although the original CIS2008 data records the actual number of employees for each firm, in the anonymised version of the data the employment is coded into three size categories: small (up to 49 employees), medium (50 to 249 employees) and large (above 250 employees). To account for size-specific effects three indicator variables were created.

**Enterprise group**

A group consists of two or more legally defined enterprises under common ownership. Each enterprise in the group can serve different markets, as with national or regional subsidiaries, or serve different product markets. The head office is also part of an enterprise group. Being part of an enterprise group is represented by an indicator variable.
**Market reach / competition**

Categorisation of geographical markets for which the enterprise sell goods/services, with four options available in the data:
- Local / regional
- National
- Other EU
- Other non-EU

The information about markets that a firm serves and whether a firm is exporter can be linked to size of the market and to degree of competition faced by the firm, with expectation that the firm has to perform better or be innovative in order to operate on highly competitive international markets. It is possible to construct a single discrete variable representing degree of competition (e.g. 1 to 4), however, such specification would impose, ex ante, a linear relationship between the extent of the market and the firms' performance and deprive the model of some flexibility, and therefore the four indicator variables are retained and used within the model.

**Sources of information**

Information what sources of information a firm was accessing in relation to its innovation activities allows categorising them and estimating importance of different information sources for R&D and innovation projects. The four broad categories of information sources include:
- Internal to the enterprise
- Market sources (suppliers, clients, competitors, consultants)
- Institutional sources (universities, governments)
- Other

**Cooperation**

Cooperation is considered as a very important activity for successful R&D and innovation. The CIS2008 provides information on type of cooperation and location of the partner, as follows:
- Other enterprise within the enterprise group
- Suppliers
- Clients
- Competitors
- Consultants
- Universities
- Government

With the possible location of the cooperation partner:
- Same country
- Other EU
- US
- China or India
- Other
Investigation of Firms' Decisions on R&D Investment

Innovation objectives

The incentives or objectives behind the innovation efforts can indicate current market opportunities as well as relate to firms' strategy. The CIS2008 asked firms about relevance of the following objectives to firms' innovation efforts:

- Increase range of goods / services
- Replace outdated products / services
- Enter new markets
- Increase market share
- Improve quality of goods / services
- Improve flexibility for producing goods / services
- Increase capacity for producing goods / services
- Improve health and safety
- Reduce labour costs per unit of output

With respect to R&D and innovation performance, the following information is present in the CIS 2008 data:

R&D expenditure

The R&D expenditure is often treated as measure of input of the innovation process. The CIS2008 collects information about types of innovation activities into which firms engaged, as well as on the actual expenditure on selected R&D categories. Specifically:

The indicator variables:

- In-house R&D
- External R&D
- Acquisition of machinery, equipment and software
- Acquisition of external knowledge
- Training for innovative activities
- Market introduction of innovations
- Other

Value of R&D expenditure on:

- In-house R&D
- Purchase of external R&D
- Acquisition of machinery, equipment and software
- Acquisition of external knowledge

7.2 Data limitations

The main limitation of the study is its inability to observe the relation between firms' R&D activity and firms' characteristics over time. The limitation stems from the CIS data re-sampling the set of firms for each wave of the data collection. In effect, each wave of data, although structurally representative, does not allow for observing the same establishments over time, and to link their
Investigation of Firms’ Decisions on R&D Investment

behaviour with their past decisions or with varying economic environment. Instead the study focuses on a cross section of firms for the period 2006-2008.

In addition, the CIS survey does not contain information about the amount of public funding provided but merely if funding is received by the firm and from which source (the questionnaire provides simple yes/no answers). Likewise, the CIS survey does not contain information of the amount of export or the degree of cooperation that a firm undertakes. Systematic differences in the amounts given by the various funding bodies could influence the results. Hence, in this study only the effects these firm characteristics being present at the firm can be estimated. Systematic differences in amounts of funding or export, or in the degree of cooperation across firms would not be captured by the CIS data and could therefore influence the results.

7.3 Model specification and estimation technique

Decision to engage into R&D

The first model aims to estimate probability of firms’ continuous engagement into R&D activities, that is \( P(\text{rndc} = 1|x_1) \), where \( \text{rndc} \) is indicator variable of firm \( i \) continuous engagement into R&D, and \( x_1 \) denotes full set of explanatory variables, and is written as:

\[
\text{rndc}_i = x_1, \beta_1 + e_1,
\]

(1)

Where index \( i \) represents firms, \( \beta_1 \) is a vector of estimated parameters, and \( e_1 \) is an error term. The equation (1) is implemented with binary response Probit model in STATA with maximum likelihood technique. Further estimated marginal effects of the Probit model, given that all covariates used are indicator variables, are interpreted as change in probability in engagement into R&D resulting from change in the binary explanatory variable from 0 to 1. The marginal effects are conditional on means of other variables.

Choice of R&D expenditure

The second step models firms’ decision related to the amount of resources dedicated to the R&D activities. Because a large proportion of firms report no spending on R&D activities, a standard linear model applied on the data would yield estimates biased towards the zero values. To correct for the bias which can occur due to the data being censored, this part of the model builds on a Heckman correction (Heckman, 1979) or Tobit (Tobin, 1958) type 2 (Amemiya, 1984) model.

Conditional on firm \( i \) performing and/or reporting R&D, the equation (2) below determines the amount of resources devoted to R&D:

\[
\text{rndi}_i = \begin{cases} 
\text{rndi}_i^* = x_2, \beta_2 + e_2, & \text{if } \text{rnd}_i > 0 \\
0 & \text{if } \text{rnd}_i = 0 
\end{cases}
\]

(2)

Where \( \text{rndi}_i^* = \text{rndi} \) is the actual research expenditure for firm \( i \) if this firm does research (i.e. if \( \text{rnd}_i > 0 \)); \( x_2 \) is the vector of explanatory variables, and \( e_2 \) is the error term.

The R&D expenditure, \( \text{rndi} \), is calculated as logarithm of R&D expenditure in thousands of Euros (or equivalent) per employee. Because significant share of the firms does not report any R&D expenditure and, because \( \log(0) \) does not exist and would lead to generation of missing observation and omission of the records in estimations, the intensity is calculated as:

\[
\text{rndi}_i = \log \left( 1 + \frac{R \& D}{\text{emp}} \right)
\]

(3)

Formula (3) returns 0 if R&D expenditure is zero, and \( \log \) of R&D expenditure per employee for positive values of R&D expenditure.
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