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Patent-based Estimation Procedure of Private R&D: The Case of Climate Change and Mitigation Technologies in Europe

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Patent-based estimation procedure of private R&D: the case of Climate Change and Mitigation Technologies in Europe[1].

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Abstract

Information on R&D expenditure of the private sector is very limited, both in term of availability and data quality, especially when interest focuses on Climate Change Mitigation Technologies (CCMTs). This has an impact on the robustness of quantitative analyses, and, consequently, on the insights deriving from them. This paper proposes a methodology to estimate R&D expenditure in firms simultaneously active in multiple technology sectors, with the focus on those contributing to the development of CCMTs. The methodological approach is applied to measure how the private sector invests in R&D dedicated to CCMTs, and how this differentiates among European countries. Further the paper proposes metrics to analyse the geographical distribution of the R&D expenditures in Multinational Corporations (MNCs) across subsidiaries located in Europe. Early findings are formulated into useful insights for stakeholders and policy makers.

The content of this paper does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the paper lies entirely with the authors.

Keywords: R&D; Patent; Invention; Climate change mitigation technologies; Energy sector

JEL: C81, O320, O340, O380, Q480

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1. Introduction

Research and development (R&D) spending in climate change mitigation technologies (CCMTs) is one of the key pillars of the European Energy Policy for 2020 and post-2020 frameworks, as stated in the Energy Union framework strategy (European Commission, 2015a, 2017). The combined effort of public institutions, academia and companies is required in order accelerate the energy transition and to contribute to a cleaner, sustainable and secure energy system. In particular, the private sector, with its capacity and willingness to invest, plays a crucial role in this process (European Commission, 2010; OECD, 2014). For instance, concerning the energy technologies in the Energy Union strategy, private R&D investment is identified as a key indicator to show progress already made in the transition to a low-carbon, secure and competitive energy system and to design future actions (European Commission, 2015b). However, in order to mobilise private investment in specific technological and geographical areas via appropriate policies, policy makers need insights on how the private sector invests in R&D and what triggers or hinders this activity. In the specific sector of CCMTs, the measurement of private R&D investment is proven to be difficult, due to lack of data availability and quality (European Commission, 2015b; Sagar and Holdren, 2002). This difficulty is greater in the case of large companies that are active in multiple countries and in multiple technology areas. Consequently, the availability of detailed evidence is very low, and cannot effectively support policy-making process when the latter needs to be tailored to specific geographical and technological areas.

The methodology presented in this paper works around these difficulties. A tailored patent analysis, coupled with available companies' information, permits the estimation of the R&D expenditure of distinct firms simultaneously active in multiple technology sectors. This framework provides information on (i) the R&D investments in the private sector concerning CCMTs, both at European and country level, and (ii) the geographical spread, among subsidiaries, of the R&D expenditures in multinational corporations (MNCs). Hence, by providing an analysis of private R&D expenditures for companies involved in developing climate change mitigation technologies in Europe, this paper gives meaningful insights to assess R&D portfolios at country level, disaggregated by technology areas. Further, it proposes metrics to evaluate the concentration or globalisation of R&D in European MNCs among subsidiaries located in Europe.

The main contributions of this paper reside in two areas. It firstly introduces a new methodological approach to estimate private R&D. Although the focus of this paper is on CCMTs, the methodology is also applicable to other sectors, making the estimation procedure suitable to different research interests. Secondly, the paper presents a new and unique analysis of investment of European companies in activities related to CCMTs. It contributes to the discussion on private R&D expenditure and R&D internationalisation in Europe and it aims at supporting policy-makers in the evaluation and elaboration of policy interventions.

The structure of the paper is the following. The research context is explained in section 2. It examines the reasons why disaggregated data on private R&D expenditure are missing, and it discusses why patent data could provide a valid proxy for the estimation of R&D. The patent analysis is presented in section 3. It illustrates the way in which patent data are extracted and treated in accordance to the methodological framework presented in this paper. Section 4 introduces the methodology, by providing the mathematical formulation of the estimation procedure. Section 5 presents the data and discusses results concerning R&D expenditure in Europe related to CCMTs. It also includes an analysis on the geographical distribution of R&D investments in European MNCs. The last section summarises closing remarks and future development of the research.

2. Background

Private R&D expenditure is monitored as a key indicator of progress towards the Energy Union objectives (European Commission, 2015b). There is a clear need to gain insight on private R&D investments, considering the central role of industry in carrying out and financing innovation in the energy sector. However, this is hindered by lack of data caused by the fact that dissemination of relevant information by companies strictly depends on two factors: companies' strategies and legal obligations. According to Lantz and Sahut (2005), companies may be reluctant to disclose complete figures on the amount and destination of their R&D spending since it can unveil strategic choices. The information is thus treated as confidential, despite the fact that companies might benefit from announcing an increment in R&D expenditure, since it anticipates market growth opportunities (Sundaram et al., 1996; Zantout and Tsetsekos, 1994). This is especially the case for companies active in high-tech industries (Chan et al., 1990) or in concentrated markets (Doukas and Switzer, 1992). For what concerns the second factor, publicly-traded companies are legally bound to produce and disclose detailed periodic statements on their economic performance, filed in compliance with formal and legal standards. On the contrary, private companies with limited liability of the shareholders, albeit requested to report their accounts, are subject to dissimilar requirements[3]. In some cases, companies may even be exempt from any obligation. As a result, data sources on private R&D investments are scarce.

The main source of information on private R&D investment is the financial and non-financial documentation provided by companies. However, since annual reports and financial statements are only available for a certain number of companies, direct collection of data cannot provide a complete set of information. The issue becomes more acute when private R&D investment needs to be broken down in order to measure investment decisions in sectors characterised by intra and inter-industry heterogeneity, as for the CCMTs sector. Consequently, when R&D information is available, the sample is overly influenced by listed companies, while small and medium enterprises (SMEs) are underrepresented, even though they are recognised as important players in the innovation process, (Ortega-Argilés et al., 2009; Vervenne et al., 2014; Voigt and Moncada-Paternò-Castello, 2012). This is the case of the Innovation Union Scoreboard, which provides the R&D expenditure in the business sector under the firm activity pillar (Hollanders et al., 2016). The main drawback of this information is the lack of provision of insight on the allocation of private R&D. In effect, when R&D expenditure is available at company level, the breakdown by specific research areas is not detailed. The Statistical Classification of Economic Activities in the European Community (NACE) also poses a number of difficulties: it does not report at the level of technological detail needed and it does not provide insight in order to split investments in firms among activities, especially when companies invest in multiple sectors (Borup et al., 2013; Breyer et al., 2013; Wiesenthal et al., 2012).

Even with the shortcomings listed above, data collection is a necessary step for the construction of the dataset. However it presents a number of issues that affect the completeness and quality of the data. For example, accounts are reported in different currencies and the definition of financial years varies; figures are not published in user-friendly layouts (e.g. scanned papers in a variety of languages); documents can be downloaded only after registration; reports are only available for the latest year with no archive available and, often, they provide preliminary estimates; and in some cases, data are replaced by generic information on the announcement of the amount of a multiannual investment plan or a declaration to keep the overall level of investment constant as a specific share of the internal resources (sales or turnover). Furthermore, the ownership structure of the potential industrial players is also a factor influencing data collection and the construction of the dataset (Alkemade et al., 2015). In case of large multinational corporations (MNCs), which hold shares in subordinate entities (also called a *parent company-subsidiaries* relationship), publications report only the group's consolidated financial statement. Further details, when available, are mostly given at business/industrial line and/or geographical level. Consequently, the economic performance of specific subsidiaries or associated companies lays hidden under the overall group's facts and figures.

Few scientific studies have addressed the issue of estimating private R&D investment in the field of energy technologies. This can be attributed to both a lack of interest and on a mandate to do so, but more importantly to the lack of appropriate and readily accessible information sources. As a result, studies concentrate on specific technologies or pockets of activity, trying to derive insights from best available datasets rather than building a methodology and information sources to address the entire sector. Nevertheless, the bottom-up approach presented in Wiesenthal et al. (2012) and the top-down in Breyer et al. (2013) contribute to this research line. The first aims at estimating public and private R&D investment in the field of low-carbon energy technologies through a four-step procedure: (i) identification of key industrial players, (ii) gathering relative information on total R&D investments, (iii) allocation of R&D investments to energy technologies for each player, and (iv) summing up individual company's R&D investment by technology. The second provides two distinct estimates of private R&D investment in the PV sector from a top-down patent analysis and an estimate of the R&D workforce. The methodological approach used in this paper, aims at strengthening the third step of the procedure presented in Wiesenthal et al. (2012). It consists of using a quantitative method based on reliable data

[3] For a general overview on the EU legal framework of company reporting, see the Directives: 89/666/EEC, 2009/101/EC, 2012/30/EU and 2013/34/EU.

deriving from patent statistics. In effect, while Wiesenthal et al. (2012) use qualitative information (reports, websites, presentations, speeches, newspaper articles, direct contacts) and/or proxy-indicators (R&D employees, patent applications) to assign R&D investment to those companies that are active in more than one technological field, the approach presented in this paper uses primarily patent statistics for this purpose. Importantly, the methodology is based on the assumption that patenting activity and R&D expenditure are related to each other (Griliches, 1984, 1990; Schmookler, 1966), as also studied in the field of energy technology (Herzog and Kammen, 2002; Margolis and Kammen, 1999; Popp, 2005)

Patent data are complex and their use as proxy of inventive activity and technological progress generates controversy among the scientific community and lack of consensus between opponents and advocates (Basberg, 1987; Desrochers, 1998; OECD, 2009; Watanabe et al., 2001). On the one hand, the opponents of using patent statistics as an indicator warn that careful consideration and interpretation of the data is needed. Organisations might decide, for instance, not to patent and on the contrary, to use secrecy, alliances or short lead times to gain a competitive advantage depending on their innovation strategy (Noone, 1979). In addition, statistical distribution of patents can frequently be skewed and exhibit peculiar properties as many patents have no industrial application while a certain few can have high technical and economic value (Kuznets, 1962). Last but not least, the propensity to patent differs across countries (Pavitt, 1985) and industries (Reekie, 1973) and the different standards applied across patent offices and their evolution over time can affect patent numbers. On the other hand, patent data represent a very rich set of information, suitable to perform robust analysis, since they are "commensurable", "quantitative" and "widely available" (Haščič and Moigotto, 2015). Patent activity has been also studied as a measure of the intermediate output in the R&D process (Hausman et al., 1984), where the so called *lag structure* is observed (Wang and Hagedoorn, 2012). It means that current patent activity is mostly explained by recent R&D rather than older R&D, exhibiting knowledge depreciation over time (Hall et al., 1986). However, as stated by Ernst (1998), more R&D does not result in more patents, but more R&D leads to a higher patent quality.

The methodology presented in this paper does not question the relationship between patent activity and R&D expenditure and its statistical significance. On the contrary, by accepting the existence of this relationship, it proposes an estimation procedure to assign R&D expenditure to firms active in multiple technology areas, focusing on those involved in the CCMTs sector. For each company, the use of patent data allows the identification of the energy technology sectors and, subsequently, the allocation of the R&D expenditure accordingly. This results in a more complete and highly granular dataset of R&D activity in energy sectors that would have not been available otherwise.

The implementation of this methodology allows the estimation of R&D that the private sector invests in activities related to support the enhancement of climate change mitigation technologies. Moreover, the analysis accommodates quantitative considerations on the level of geographical distribution of R&D, from the parent company of a MNC to its subsidiaries (Hegde and Hicks, 2008; Iwasa and Odagiri, 2004). The determinants of location decision of R&D activities by MNCs are addressed by a large body of literature. Carlsson (2006), surveying a number of works focused on internationalisation of innovation activities, offers an interesting categorisation of the main contributions. The author identifies three main groups of studies: (i) empirical studies of internationalisation of innovation systems, (ii) internationalisation/globalisation of (private) R&D, and (iii) institutional barriers to internationalisation. Accordingly, the application presented in this paper can be placed in the second research field. The decision to transfer R&D activities abroad is mainly driven by market-seeking and knowledge-seeking objectives (Rahko, 2016; Siedschlag et al., 2013). More specificatelly, the strategy to pursue R&D in a given location is motivated by the different support that the host countries could provide: better policy regimes (Kumar, 1996), market opportunities (Kuemmerle, 1999), knowledge spillovers (Chung and Alcácer, 2002; Feinberg and Gupta, 2004), increasing collaborations (Granstrand, 1999), and networking opportunities (Schilling and Phelps, 2007). Furthermore, globalisation of R&D through subsidiaries is also carried out because of increasing possibilities of knowledge and technology transfer between parents and subsidiaries (Un and Cuervo-Cazurra, 2008).

3. Patent analysis

OECD defines patents as "a means of protecting inventions developed by firms, institutions or individuals, and as such they may be interpreted as indicators of invention" (OECD, 2009). OECD continues: "patent can be seen […] as both inputs and outputs in the invention process" and this "makes patent data a useful bridge between R&D data and innovation data" (OECD, 2009). The use of patent data in this paper focuses on the *input-side* of the bridge, namely the connection between patent and R&D. In this context, patent statistics are utilised in order to obtain a "measurable" proxy of the inventive work, in agreement with the input-output model summarised in Freeman and Soete (1997, p. 7). There is no single way to elaborate patent statistics. Rather, each methodology reflects the research question addressed (Martinez, 2011). This section explains the way in which patent data are extracted and treated within the methodological framework presented in this paper, and why.

Patent data are retrieved from PatStat (2017 Spring Edition). Since the objective is to estimate R&D expenditure through patent statistics, only the applicants are considered; applicants are the owners of the patent[4] and, consequently, those that invest and finance R&D. Conversely, the inventors are the physical persons researching and developing that invention (De Rassenfosse et al., 2014; De Rassenfosse et al., 2013). Hence, name and residence country of each applicant is considered in order to have information on the organisation financing R&D and its location. In many cases, an applicant is the organisation, which employs the inventor; however it can happen that a physical person is both the applicant and the inventor. Therefore, the sector classification is used to distinguish between different types of applicant (company, individual, university, government no-profit organisation).

An applicant can apply for one or more patents. Patent applications are submitted to patent offices. In order to patent one invention, an applicant can follow different routes (national, regional, or international). In this study, since the focus is on the R&D-patent connection, the analysis takes into account all applications in all offices, without any restriction regarding national or international route. The reasoning resides with the fact that the focus is on where and when the R&D has been financed rather than where and when an applicant seeks protection for the invention. Further, since the estimation procedure aims to quantify the R&D expenditure using patenting activity as a proxy, it is necessary to consider all routes; otherwise, were some application to be excluded, the overall R&D effort would be underestimated.

Each patent application has a priority date which corresponds to the filing date of the earliest application in a patent family. A patent family is a group of patent applications, which share the same priorities and so they refer to the same invention (De Rassenfosse et al., 2013; Dechezleprêtre et al., 2017; European Patent Office, 2016a; Hinze and Schmoch, 2004). Therefore, in this study, the concept of patent families is associated to the concept of inventions. The combined analysis of patent families and priority years implicitly takes into account the time-lag between R&D expenditure and invention/patent production. Patent applications grouped in one patent family, which share the same priority year, may be filed in later years. According to our calculations, around 53% of patent applications are filed one year after the priority year of the correspondent patent family and about 11% of them are filed two or more years after. Only 36% of patent applications have the same filing and priority year. Since the estimated R&D is based on the priority year of the patent family, the methodology presented in this paper is able to capture the time-lag between R&D and production of inventions, which happen at least one year later for the 64% of the cases.

Technology classification of inventions is done through the Cooperative Patent Classification (CPC) scheme. The CPC is a classification of patent applications according to technological sectors; one or more CPC codes are assigned to the same patent application. The scope of this research is limited to patent applications belonging to the Y02 and Y04 schemes. They concern patents related to Climate Change Mitigation Technologies (CCMTs) (Rudyk et al., 2015; Veefkind et al., 2012). In summary, patent data are extracted in order to measure inventions (patent families) in a specific technology area (Y02 and Y04 schemes) for which the R&D investment is assigned to a specific year (priority date). Moreover, data extraction is designed to contain information on how many participants have been involved in these R&D projects (names and sectors of the applicants) and which countries they are based in. The R&D activity can involve one or more organisations

[4] Patent ownership might change over time (Serrano, 2010), as studied in the semiconductor and electronic sectors (Grindley and Teece, 1997), or in respect to academic inventions (Sterzi, 2013). However, the patent analysis does not consider this possibility, since this issue goes beyond the scope of this paper.

from different countries and it can impact one or more technological fields. In order to avoid multiple counting and to define a better proxy for inventions, the well-established technique of fractional counting is used (OECD, 2009). It consists of assigning equal proportion of the invention to each participant and in relation to all technologies tackled in the same family. As an example, we assume that company A and company B, respectively from country X and Y, submit two patent applications regarding two different technological sectors, T1 and T2, and these applications belong to the same patent family. By fractional counting, company A in country X contributes 25% for the part of the invention relative to technology T1, and another 25% for technology T2, while the effort of company B in country Y is 25% of the total for both T1 and T2. Therefore, the sum of fractional by organisation or by country quantifies the respective total inventive activity in relation to a specific technology.

However this calculation does not produce reliable results when raw data are used as extracted from PatStat because of issues with data "accuracy and completeness" (European Patent Office, 2016a). Consequently, before the fractional counting, a data clean-up process is needed in order to eliminate blank entries, typos, errors and inconsistencies, in applicant's characteristics (name, sector and country). This process follows the steps developed in Pasimeni and Fiorini (2017) that consists of an automatic procedure followed by manual corrections. The necessity of the data cleaning process, also acknowledged in literature (Alkemade et al., 2015; Balconi et al., 2004; De Rassenfosse et al., 2013; Fiorini et al., 2017; Lissoni, 2013), is illustrated in Fig. 1. It shows the difference in the number of patent applications related to CCMTs per country in 2012 before and after processing. When raw data are used, more than one hundred thousand patent applications are not assigned to any country. This number decreases to less than two thousand after the data cleaning process. For some countries, this process has a considerable impact. Data cleaning allows the allocation of near 37 thousand patent application to China and almost 42 thousand to Japan. Other countries show a notable increase in the number of patent applications: e.g. Italy +59%, Netherlands +33%, Switzerland +26%, Denmark +20% and Germany +19%. It follows that patent analysis based on raw data could result in misleading conclusion and that data cleaning is a necessary, rather than a valuable or optional step.

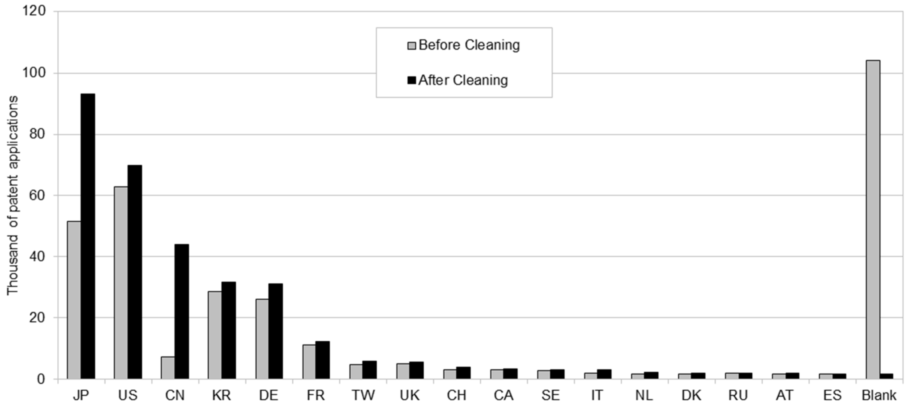

Fig. 1 Number of patent applications in CCMTs in 2012. Top countries, before and after data cleaning

In conclusion, the patent analysis consists of three steps: (i) extraction of patent data from PatStat, (ii) data clean-up and (iii) fractional counting. The resulting dataset is a list of about 112,000 organisations (company, university, government non-profit) located in 140 different countries and more than 310,000 individual applicants. The list includes organisations and individuals that have participated at least in one invention regarding CCMTs (Y02 and Y04 schemes) in the period of time 2000-2013[5]. For each organisation and individual, the fractional count quantifies the yearly inventive activity in a specific energy technology area within the CCMTs sector. The inventive activity is the input for the estimation procedure of private R&D presented in the following section.

The estimation procedure focuses only on companies (around 25% of the total dataset). It uses the company's energy technology fractional as a proxy of inventions produced and financed by a company in a

[5] The dataset does not cover years after 2013 because, for subsequent years, it is not complete. The European Patent Office (2016b) states that, with a high probability, data are complete up to 42 months before the last available edition.

specific energy technology area. In other words, the patent analysis results in a list of companies active in developing CCMTs and their related number of inventions. These companies, when possible, are grouped under the respective parent company, thereby defining the entire structure of MNCs and their parent-subsidiaries relationships. The grouping exercise is done manually by means of information accessible through the ORBIS Europe database, a Bureau van Dijk (BvD) product, and other online sources. When available, the annual R&D expenditure is associated to each MNC. R&D data are collected by means of the following routes: (i) the EU Industrial R&D Investment Scoreboard[6] and (ii) financial statements and companies' documents. If the available data on financial statements cover more than one year, a corresponding time average is applied. If the company follows an accounting standard not based on the calendar year (e.g. in the United Kingdom), the expenditure for the calendar year is assumed. When alternative currencies are used, they are converted to Euro based on Eurostat annual bilateral exchange rates.

4. Patent-based estimation procedure for private R&D

The estimation procedure of private R&D expenditure at company and technology level is built on following mathematical steps. These imply an extensive cross-reference between the companies' data and the results from patent analysis. As described at the end of section 3, the output of the patent analysis is a list of companies active in the CCMTs sector. For each company i in this list the following two information are considered: the residence country, c_i, and the CCMTs technology area e in which it is active. Thus, the annual company energy technology fractional, or the number of inventions produced and financed in one year t, is defined as:

(1) $F_{i,c_i,e,t}$

Some companies might also be active in other non-CCMTs technology areas r, therefore, given E the number of CCMTs technologies tackled by a single company and R the non-CCMTs technologies,

(2) $$F_{i,c_i,t} = \sum_{e=1}^{E} F_{i,c_i,e,t} + \sum_{r=1}^{R} F_{i,c_i,r,t}$$

measures the company's overall financed inventing/patenting activity at time t, regardless the breakdown by technology[7]. In order to disentangle the total R&D of a group, or MNCs, across all subsidiaries, when possible, companies are grouped under the respective parent company (grouped companies are indicated as i_g, while the other with i_0). For each group g the following information is available: the residence country c_g (country of the headquarter of the group) and the sector of economic activity[8] s. Therefore, since one company i_g belongs to a single group g, the total number of financed inventions of the group g at time t is computed as:

(3) $$F_{g,c_g,s,t} = \sum_{i_g=1}^{n} F_{i_g,c_i,t}$$

where n is the number of subordinate companies in the group g. Equation (3) represents the total inventive activity of a single MNC, regardless of technology classification. The total group's R&D at time t is known and it is defined as:

(4) $RD_{g,c_g,s,t}$

[6] http://iri.jrc.ec.europa.eu/scoreboard.html
[7] Information in (2) is obtained again from PatStat though a different extraction query, specificity designed for this purpose. See section 2.5 in Pasimeni and Fiorini (2017).
[8] Information of sectors is already present in the Industrial R&D Investment Scoreboard. Authors have done a further harmonisation in order to remove inconsistencies among editions.

Given (3) and (4), for every year t, it is possible to calculate the total R&D expenditure and the total financed inventive activity for all combinations of countries c_g and sectors s as follows:

$$(5)\ RD_{s,c_g,t} = \sum_{g=1}^{z} RD_{g,c_g,s,t}$$

$$(6)\ F_{s,c_g,t} = \sum_{g=1}^{z} F_{g,c_g,s,t}$$

where z represents the number of groups active in the same sector and resident in the same country. Based on (5) and (6), it is possible to calculate the sector unitary expenditure for each country and for a given year as follows:

$$(7)\ UC_{s,c_g,t} = \frac{RD_{s,c_g,t}}{F_{s,c_g,t}} = \frac{\sum_{g=1}^{z} RD_{g,c_g,s,t}}{\sum_{g=1}^{z} F_{g,c_g,s,t}}$$

This value represents the R&D expenditure needed to produce one invention in country c_g and in respect to a specific sector of economic activity s, at time t. The unitary expenditure in (7) is then associated to all groups belonging to the specific sector s and resident in country c_g, therefore,

$$(8)\ UC_{g,c_g,s,t} = UC_{s,c_g,t}$$

Given (1) and (8), for every year t, it is possible to estimate the R&D expenditure for the n subsidiaries that are subordinate companies of the z groups active in sectors s. Further, since the number of inventions is known at technology level, the company R&D is estimated with this level of detail:

$$(9)\ RD_{i_g,c_i,e,t} = UC_{g,c_g,s,t} \cdot F_{i_g,c_i,e,t}$$

The procedure in (1) – (9) allows the estimation of the R&D expenditure for a portion of the companies in the list derived from section 3, i_g. To be precise, these companies are subsidiaries of MNCs for which R&D data is available, therefore this procedure notably contributes to the evaluation of MNCs and their approach to R&D investments in CCMTs. In order to complete the estimation procedure for the remaining companies in the list, i_0, a subsequent estimation procedure is necessary. The second part of the mathematical steps, uses the outcome of the previous part and it begins with the calculation of the total R&D expenditure and the total number of financed inventions, for all combinations of CCMTs e and countries c_i, at time t, as follows:

$$(10)\ RD_{c_i,e,t} = \sum_{i_g=1}^{x} RD_{i_g,c_i,e,t}$$

$$(11)\ F_{c_i,e,t} = \sum_{i_g=1}^{x} F_{i_g,c_i,e,t}$$

Here, x is the number of subsidiaries i_g resident in country c_i, for which the R&D expenditure is estimated though equation (9), at time t and for the CCMTs technology area e. Consequently, for every year t, the technology unitary expenditure at country level is calculated as follows:

$$(12)\ UC_{e,c_i,t} = \frac{RD_{c_i,e,t}}{F_{c_i,e,t}} = \frac{\sum_{i_g=1}^{x} RD_{i_g,c_i,e,t}}{\sum_{i_g=1}^{x} F_{i_g,c_i,e,t}}$$

This represents the R&D expenditure necessary by companies in country c_i to produce one invention in respect to a specific technology e, at time t. Eventually, for those companies in the list not covered by equation (9), e.g. those not grouped under any MNCs, the annual estimated R&D at technology and country level is obtained as follows:

$$(13)\ RD_{i_0,c_i,e,t} = UC_{e,c_i,t} \cdot F_{i_0,c_i,e,t}$$

The major contribution of the proposed estimation procedure is addressing the lack of R&D data broken down by company and technology, especially for those MNCs that include subsidiaries located around the globe. In order to achieve this result, this methodology uses patent statistics that permits the inclusion of cross-country, cross-sector and cross-technology heterogeneity[9] in the mathematical formulation. Nevertheless, this relevant outcome is based on some assumptions that need further explanation. The two processes (1) – (9) and (10) – (13) are complementary and together, they allow the estimation of the R&D expenditure for the full list of companies active in the sector of CCMTs, detailed per technology and year. The two parts of the estimation procedure aim at calculating two distinct unitary expenditures per invention that are used to estimate R&D per company and technology. The first one is the sector unitary expenditure, in equation (7). It considers the specificities of MNCs, such as the residence country of the parent company as well as the sector of economic activity. However, it does not take into account characteristics of subsidiaries, namely country and technology area, for which the same unitary expenditure is associated, as in equation (9). In contrast, the technology unitary expenditure, in equation (12), captures both cost determinants: country and technology area of companies. In fact, it sums R&D and inventive activity at technology and country level, and it calculates their proportion. This value is then associated to the remaining companies, as in equation (13). In conclusion, the mathematical procedure is built on subsequent steps that permit the estimation of private R&D expenditure considering as many cost determinants as possible.

[9] Please see Annex I to more insights on the heterogeneity.

5. Data description and results

This section presents the data structure and discusses results deriving from the application of the methodology described in the paragraphs above. From the available dataset of organisations present in PatStat, only companies located in Europe[10] are considered. In total, there are around 19,000 distinct companies in the CCMTs sector between 2003 and 2013, corresponding to about 3,000 active companies every year, considering that some of these can be continuously active over the period analysed. The CCMTs sector is divided by technology area through the use of CPC codes. Table 1 below summarises the codes analysed further in this paper.

CPC Groups - description		Label
Y02B	Indexing scheme relating to climate change mitigation technologies related to buildings, e.g. including housing and appliances or related end-user applications	Buildings
Y02C	Capture, storage, sequestration or disposal of greenhouse gases [GHG]	CCS
Y02E	Reduction of greenhouse gases [GHG] emission, related to energy generation, transmission or distribution	Energy
Y02P	Climate change mitigation technologies in the production or processing of goods	Goods
Y02T	Climate change mitigation technologies related to transportation	Transportation
Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	Waste
Y04S	Systems integrating technologies related to power network operation, communication or information technologies for improving the electrical power generation, transmission, distribution, management or usage, i.e. smart grids	Smart-grids

Table 1 List of technology area defined through CPC aggregation

Europe shows a different distribution of companies among countries (Fig. 2) and technology areas (Fig. 3). Further, quantity of active companies also varies over the years. Germany is the country where the majority of companies active in the CCMTs sector reside. This predominance is stable over time and illustrates the importance of the private German sector in developing CCMTs. All countries show an increasing trend in the number of companies until 2010, followed by a decline in 2013. With respect to technology areas in the CCMTs sector, energy has the highest number of active companies, although in 2004, the most populated area was that of production and processing of goods. Companies are counted more than once if simultaneously active in multiple technology areas.

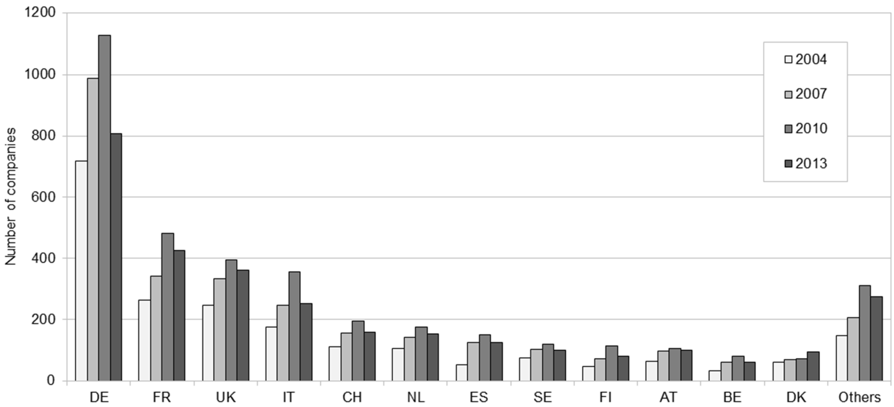

Fig. 2 Number of companies per country in Europe

[10] In this paper Europe is defined as the 28 Member States of the European Union plus Iceland, Norway and Switzerland.

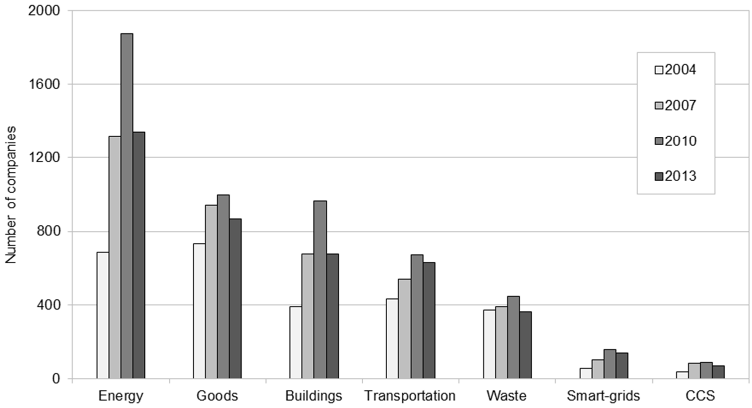

Fig. 3 Number of European companies per technology area

European R&D expenditure differentiates among technologies, and its total value increases over years (Fig. 4). The latter confirms the increasing propensity of the private European sector to invest R&D in activities related to CCMTs. R&D expenditure related to energy and transportation constantly covers more than 60% of the total. This indicates that, in the years examined, European companies have considerably invested to develop climate change mitigation technologies related to energy (generation, transmission and distribution) and transportation. Interestingly, the R&D invested in transportation, is higher than that in energy, despite the fact that the number of companies in this sector is lower (see Fig. 3). Consequently, the R&D effort per company changes in relation to the technology in question. In 2013, a company active in developing CCMTs related to transportation would have spent about 14 EUR million on average, in comparison to the 5 EUR million spent on average by a company active in energy.

The total R&D expenditure in CCMTs has more than doubled over the years analysed. Nonetheless, in two instances, the total European R&D budget decreased between two consecutive years, respectively 2010-2011 and 2012-2013. While the first drop is mainly due to a reduction of investments in the building area (-23%), the second one is due to the combined effect of reduction in R&D expenditure in energy (-15%) and transportation (-12%).

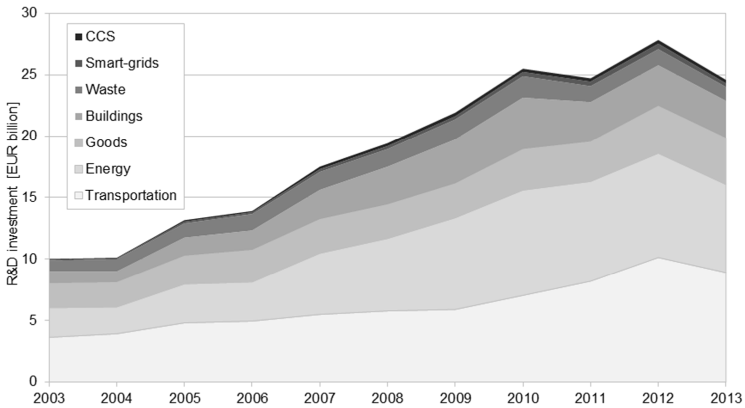

Fig. 4 Private European R&D investment per technology area, 2003-2013

Among the European countries Germany has the highest R&D expenditure, about three times bigger than in France, the second largest R&D investor, while all the remaining countries spend, on average, less than one EUR billion each. Nevertheless, it is interesting to analyse the countries portfolio regarding private investment in CCMTs (Fig. 5). On average, companies in Germany, France and Sweden spend more than 40% of their CCMTs R&D budget in activities related to transportation. In contrast, Denmark (61%) and Spain (55%) have their maximum expenditure in the energy area. These results reflect the so-called country *technological specialisation* (Archibugi and Pianta, 1992) or *national system of innovation* (Lundvall et al., 2002): the private sector in specific countries is inclined to invest more in CCMTs sectors where the level of country specialisation is higher.

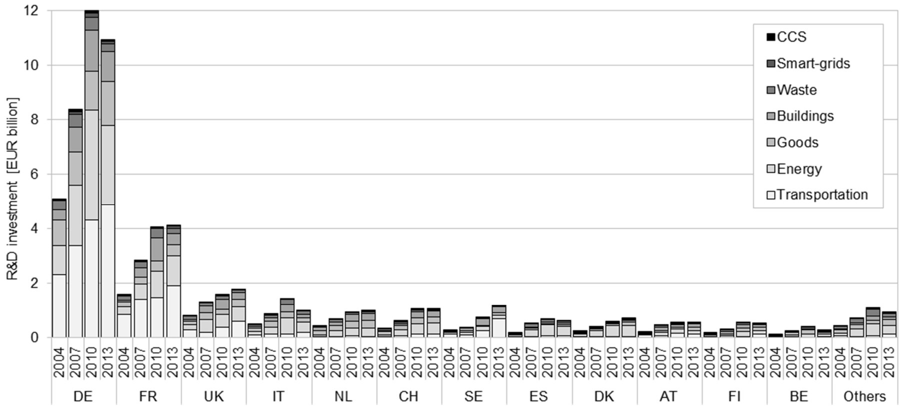

Fig. 5 Private R&D investment per country and technology area

A way to validate the methodology is to check whether the estimation procedure provides comparable results to already existing analysis on the cost per invention. Table 2 below shows technology unitary costs, as calculated in equation 7. These values represent the estimated effort in terms of R&D expenditure by the European corporate sector to produce one invention in a specific technological area. They indicate that inventive activities require a different R&D effort, in relation to which technology is tackled and in which year.

$UC_{e,ci,t}$	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Buildings	2.72	2.50	3.48	3.74	4.33	4.58	4.63	5.32	3.97	3.15	2.93
CCS	3.24	3.52	3.86	4.08	5.83	5.41	4.94	4.84	3.87	2.64	3.03
Energy	4.37	3.83	5.07	4.32	5.01	4.44	4.65	4.79	3.69	3.16	3.02
Goods	3.90	4.15	4.55	4.76	5.03	4.75	4.61	5.03	3.79	3.29	3.02
Transportation	3.17	3.18	3.76	3.51	3.25	3.08	3.12	3.38	3.20	2.89	2.70
Waste	3.61	4.07	4.75	5.63	6.27	5.38	5.82	5.95	4.31	3.62	3.28
Smart-grids	3.67	2.82	4.26	4.40	3.95	4.57	4.28	4.98	4.13	3.13	2.80

Table 2 Technology unitary costs, EUR million

Apart from the individual unitary expenditure per technology area, an average R&D cost per inventive activity per sector can be estimated. In the case of CCMT the average R&D cost per inventive activity is estimated to be about EUR 4 million. Other studies have also tried to measure an average cost per patent. Johnson (2002) presents the R&D unitary expenditure per patent in the manufacturing sector in Germany, France and Italy[11]. The average value is about USD 4.89 million (approximately EUR 4.1 million). Berman and Woods (2002) reported the estimation of the R&D cost per patent awarded by the top four patenting companies in three different sectors in USA: manufacturing, electronics and pharmaceutical. This value is about USD 3.8 million (approximately EUR 3.2 million)[12]. Even though these estimates have been derived from different assumptions and analyses and they cover different sectors, they do not differ, in order of magnitude, from the one found in this study. This comparison might strengthen further the validity of this methodology.

5.1. MNCs and globalisation of R&D

This section presents new metrics aiming at evaluating how European multinational corporations distribute R&D investments across countries in respect to the climate change mitigation technologies. The analysis is based on the first part of the estimation procedure, namely the mathematical steps (1) – (9), which analyses the relationships between parents and subsidiaries. The accuracy of this analysis depends on the grouping exercise which matches patent assignees (or subsidiaries) with the respective parent company. On average, every year the sample includes 215 European multinational corporations plus 164 non-European MNCs. These are parent companies of about 548 European subsidiaries, active in the CCMTs sector: almost 90% of these subsidiaries have a parent company located in Europe, while the rest 10% of European subsidiaries belong to non-European MNCs. Therefore, on a yearly basis, the analysis of R&D globalisation focuses on about 18% of European

[11] Data refer to the period 1996-1998. Conversion from national currency to USD has been produced
[12] Data refer to the period 1998-2000

companies active in the sector of CCMTs. The rest of the paper uses this terminology: the origin-country is defined as the country of the parent company of the MNC, hence where the headquarter is located (c_g); destination-country, instead, is the residence country of subsidiaries (c_i).

The first metric regards the MNCs exposure to CCMTs. It measures the share of the total R&D expenditure allocated to CCMTs. It can be analysed for countries (Fig. 6) and sectors (Fig. 7). Based on the yearly average of three different periods (2005-2007, 2008-2010 and 2011-2013), Denmark is the European country with the highest share of exposure to CCMTs. About 43% of the R&D budget of the Danish MNCs is allocated to activities related to climate change mitigation technologies. Spain is second (about 22%), even though the exposure to CCMTs has decreased over years. Although many other countries show increasing trends, the average European exposure to CCMTs over the period examined is about 13%.

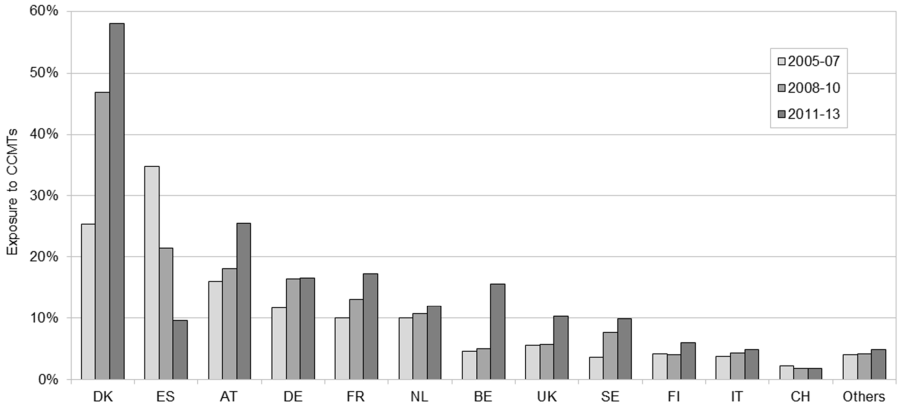

Fig. 6 R&D exposure to CCMTs per country origin of European MNCs (c_g)

The exposure to CCMTs is calculated also per sector of economic activity. In Europe it varies significantly among sectors. European MNCs working in the alternative energy economic activity, on average, allocate 67% of their R&D budget to CCMTs. This sector, along with gas, water & utilities and electricity, are the only ones with exposure to CCMTs higher than 25%, on average. This is consistent with the fact that activities in these sectors are related to CCMTs in contrast to other sectors like, for example, pharmaceutical & biotechnology or telecommunications.

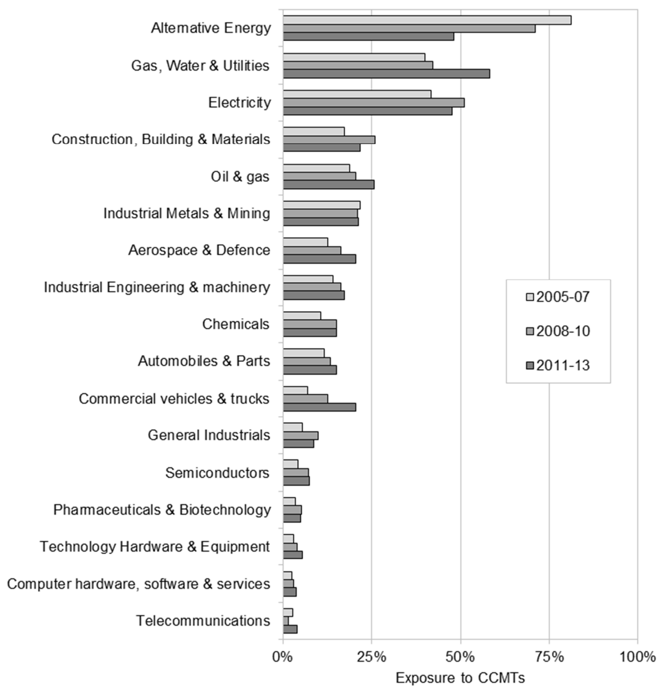

Fig. 7 R&D exposure to CCMTs per sector of European MNCs

The estimation procedure can provide very granular data at company level regarding the amount of monetary investments allocated to R&D activities in different sectors. This can also be used to test the validity of the first part of the methodology, (1) – (9). As shown above, some MNCs focus their R&D activity almost entirely to one sector. These companies are commonly defined as mono-technology companies. For example, for those companies in the alternative energy sector it is reasonable to assume that their R&D budget goes directly to activities related to CCMTs. In Fig. 8, their declared annual R&D expenditure is compared to R&D values estimated through the proposed methodology. Based on this example we draw two important conclusions on the estimation procedure: (i) it has a high level of reliability since, for mono-technology companies, the estimated yearly trend of R&D expenditures allocated to CCMTs follows the actual one (85% on average in the period analysed); (ii) it can reveal the specialisation level of a given company in one or more sectors.

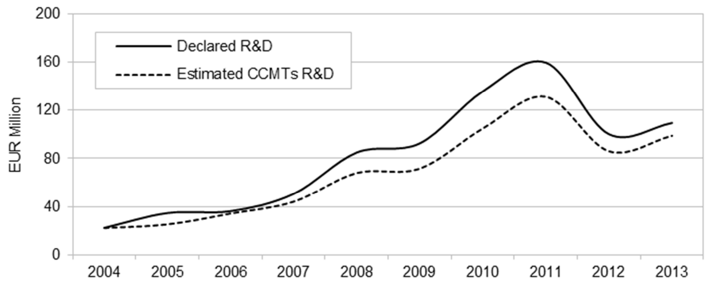

Fig. 8 Declared vs. estimated R&D in the alternative energy sector (average value). Sample size 3 MNCs

Outcomes deriving from the analysis of sector specialisation are different when multi-technology companies are taken into account. For example, Fig. 9 shows aggregated data for European companies active in the automotive sector. On average, in the period 2003-2013, only 14% of the total R&D budget has been allocated to R&D activities related to climate change and mitigation technologies. Nevertheless, in the same period, the total amount has slowly increased indicating a growing attention from the automotive sector to climate change mitigation technologies. These results are not surprising. On the one hand, the core activity for these companies is to improve technologies concerning motor vehicles, on the other hand, the shift towards more environmental strategies (e.g. R&D activity in biofuels, batteries, electric vehicles, etc.) is a clear response to the crisis occurred in this sector in 2009.

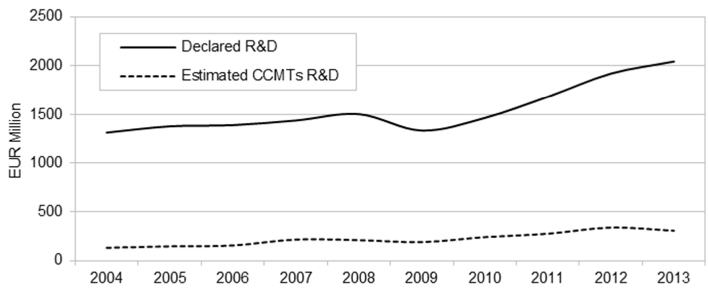

Fig. 9 Declared vs. estimated R&D in the automotive sector (average value). Sample size 20 MNCs

MNCs distribute their R&D budged geographically through subsidiaries. This propensity can be also analysed in the context of CCMTs. Fig. 10 shows, on average, the share of the CCMTs R&D budget invested by MNCs in the same origin country ($c_g=c_i$). This share is very high for many European countries, meaning that the R&D investments in CCMTs for the most part do not flow across countries, similar to findings in Laurence et al. (2015). This is particular evident for Spain, Germany, Finland, Denmark, France and Italy: corporations resident in these countries invest, on average, more than 75% of their R&D in subsidiaries located in the same country. The decision to maintain CCMTs investments in the same origin country might be due to a greater benefit of in-house R&D in this specific sector, or to a higher difficulty of knowledge transfer and management among subsidiaries and parent companies located in different countries. However, this strategic decision is not common to all MNCs. In fact, corporations resident in the Netherlands, the United Kingdom and Austria, allocate their CCMTs R&D mostly to subsidiaries that are not in the same origin country (either in other European countries or in non-European countries). This investment strategy could be related to the fact that many multinational corporations have decided to base their fiscal residency in countries where the fiscal regime is more favourable, while retaining R&D facilities and subsidiaries elsewhere.

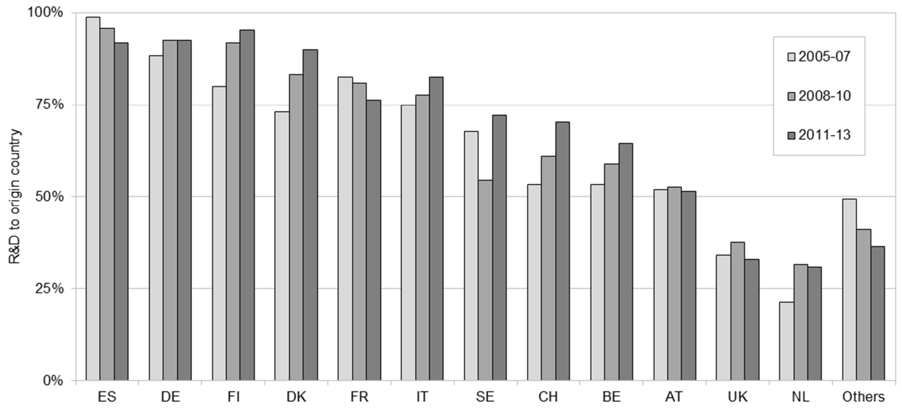

Fig. 10 Share of R&D allocated by MNCs to subsidiaries in the same origin country ($c_g = c_i$)

Despite the low inclination to invest in CCMTs R&D in subsidiaries located in countries different from that of the parent one, some companies still receive R&D investment from *foreign* MNCs. Fig. 11 shows the share of R&D per destination country, coming from parent companies located elsewhere ($c_i \neq c_g$). Companies in Austria and Belgium, respectively, receive, on average, 68% and 63% of their total R&D budget from MNCs located in different countries. In contrast, the share of *foreign* investment in Germany, the Netherlands, France, Denmark and Finland is very low, less than 15% of the total.

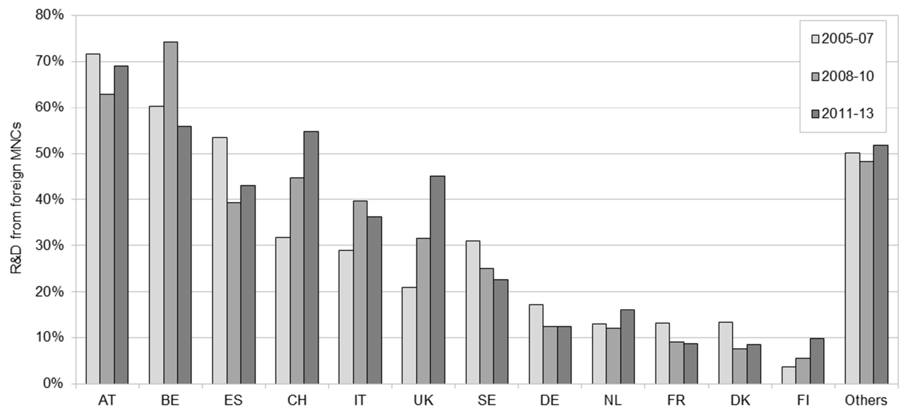

Fig. 11 Share of R&D allocated to subsidiaries located in countries different from the origin ($c_i \neq c_g$)

It is interesting to compare these last two metrics. For example, companies located in the Netherlands do not receive large amount of R&D investment in the CCMTs from *foreign* MNCs. Furthermore, Dutch MNCs invest large proportion of their budget to companies located in different countries. To further investigate this relation, it is important to see the flow of R&D from origin-countries (c_g) to destination-countries (c_i), as matrix in Fig. 12 shows. On average, in the period 2003-2013, Germany is the destination-country where MNCs prefer to allocate the majority of their CCMTs R&D investment (39%), followed by France (13%) and Switzerland (9%). MNCs located in the Netherlands, are the most active in supporting R&D abroad (32%), with particular interest in subsidiaries in Germany (16%) and France (9%). These results are in line with findings in Guellec and De la Potterie (2001): accordingly they affirm that international connections often depend on country proximity and on similarity in technological specialisation and language (see for example France primarily investing in Germany, Switzerland and Belgium). Therefore, values in Fig. 12 can be used as indication of the level of connections between parent companies and subsidiaries located in different countries in respect to the CCMTs sector.

		Destination												
		AT	BE	CH	DE	DK	ES	FI	FR	IT	NL	SE	UK	Others	
Origin	DE	2%	0%	0%		1%	0%	0%	1%	0%	0%	4%	1%	1%	11%
	FR	0%	3%	6%	11%	0%	1%	0%		0%	0%	0%	1%	3%	25%
	NL	0%	0%	0%	16%	0%	1%	0%	9%	3%		0%	3%	0%	32%
	UK	1%	0%	0%	5%	0%	1%	0%	0%	0%	0%	0%		2%	9%
	Others	1%	1%	3%	7%	0%	1%	1%	3%	1%	1%	1%	1%	2%	22%
		4%	4%	9%	39%	2%	5%	1%	13%	4%	2%	5%	5%	8%	

Fig. 12 Share of R&D flow from origin-destination. Average values in period 2003-2013 ($c_g \neq c_i$)

MNCs take the strategic decision to allocate R&D investment to subsidiaries in different locations because of characteristics of the destination-country. This decision is technology- or sector-dependent (Malerba, 2002; Malerba and Orsenigo, 1996): country attractiveness varies in relation to which technology MNCs want to support through R&D investments. Fig. 13 shows, for each technology area, the most prominent destination countries for the R&D investment in CCMTs allocated by MNCs resident in different countries. Germany is first in almost every technology area, particularly in energy and transport. Exceptions are CCMTs related to CCS, where Switzerland is the top destination-country with more than 50% of R&D investment provided by *foreign* MNCs, and CCMTs related to smart-grids, where Spain is the top destination-country (26%). In the remaining technology areas, although Germany remains the favourite destination, other countries also have elevated high level of attractiveness: this is the case of Italy in buildings, Belgium in goods and Italy, the Netherlands and Belgium in waste technologies.

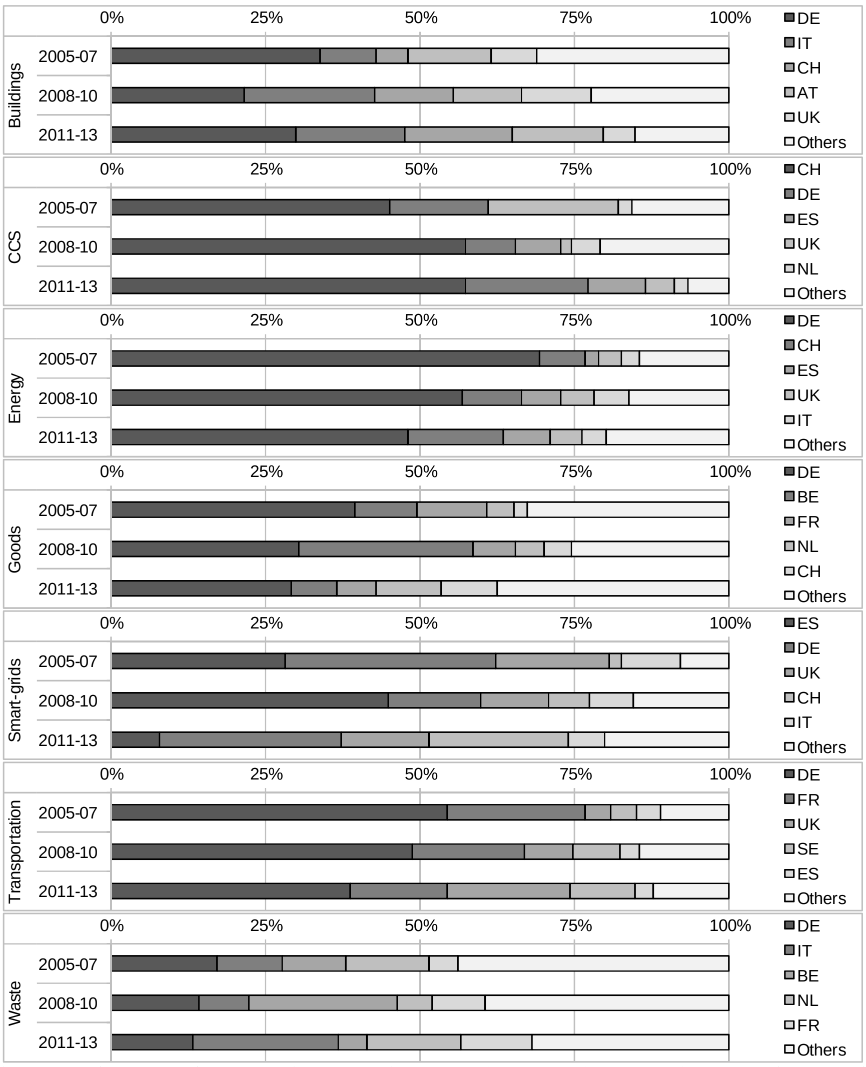

Fig. 13 Country attractiveness: share of R&D allocated by foreign MNCs ($c_i \neq c_g$)

6. Conclusion and future steps

This paper has proposed a new methodological approach aiming at the estimation of private R&D investments in Europe. It starts from a detailed patent analysis to calculate the number of inventions concerning climate change and mitigation technologies (CCMTs). Inventions are then used to estimate R&D expenditure accordingly. The estimation procedure of R&D is built on data available for several multinational corporations (MNCs) and on the relative corporate structure, defined though the relations between parent companies and subsidiaries.

There are several advancements achieved with respect to previous works. The dataset is constructed using a rigorous circular feedback between patent data and companies' information. A clear and robust estimation procedure is defined. This improves the quality and quantity of data and includes the contribution to R&D of both large firms and small and medium enterprises. The method – here demonstrated for CCMTs, is applicable to other topics, without specific restrictions on the nature of the companies, type of business and industrial sectors. The resulting information set can provide policy makers with relevant insights on specific sectors and/or countries, clustered according to territorial or technological characteristics.

In this paper the methodology has been applied to the case of CCMTs in Europe in order to evaluate the R&D investments of the private sector. In the last decade the European companies have made considerable efforts to enhance R&D activities in these technology areas. In the period 2003-2013, the budget allocated has more than doubled, in particular in R&D dedicated to climate change mitigation technologies related to energy (generation, transmission and distribution) and transportation. Countries' portfolios of R&D investments, detailed by technology areas, differ significantly. Germany has the largest amount of private investment in CCMTs, allocated across all technologies examined. In other countries, on the contrary, companies focus their R&D budget primarily to a predominant technology area.

The methodology also provides data useful in the calculation of metrics regarding the geographical distribution of R&D investments in Europe. These consider the residence country of the MNCs (origin country) and the location of their subsidiaries throughout the world (destination country). The exposure to CCMTs indicates that MNCs, on average, allocate only 13% of their budget to enhancing these technologies. However, there are differences among countries and sectors of economic activity. The limited budget allocated by European MNCs to CCMTs is not globalised: on average, about 66% of these investments remain in the same origin countries. However, this trend is country-dependent. The Netherlands is the origin country from where the highest share of R&D related to CCMTs is distributed to other European countries (32% of the total), while Germany is the destination country where the highest share of R&D is allocated by foreign MNCs (39% of the total). However, country attractiveness is technology-dependent.

The methodology has proposed a number of advancements in estimating private R&D. However, it still contains a number of assumptions that need to be borne in mind and will be the subject of further improvement. The list of companies active in the CCMTs derives from PatStat. This means that if a company is performing R&D activities related to one or more of these technology areas and it has not patented any invention, this company is not considered. Although this might have an impact on the total R&D budget, this is assumed as not significant, since the major investors in this sector are present in the list. The name of every company in the list is given in PatStat. Although the data cleaning process introduces a major improvement in terms of data accuracy and completeness, it still does not guarantee that all company names are accurate. This creates complications in the definition of the structure of multinational corporations, since some subsidiaries may not be easily recognised by name. This is particularly evident when both MNCs and subsidiaries are located outside Europe. Finally, R&D data are available for many corporations, for which the main sector of economic activity might not be related to CCMTs, and hence their patenting activity is not registered under this sector. As a result, subsidiaries belonging to these MNCs are also not listed and, despite the R&D information being available, cannot be included in the estimation procedure. Consequently, the continuation of this research requires the refinement of the structure of MNCs, by constantly updating the existing ones and adding more in the sample. This will allow the enhancement of the estimation procedure and the possibility to provide better and more robust insights for stakeholders and policy makers.

Annex I

Scatter plots in Fig. 14 show the relative ranking of European companies with respect to their estimated R&D and patented inventions in 2012. These show the strength of the estimation procedure in capturing both company and technology heterogeneity. On average, there is a strong and positive correlation between inventions and R&D.

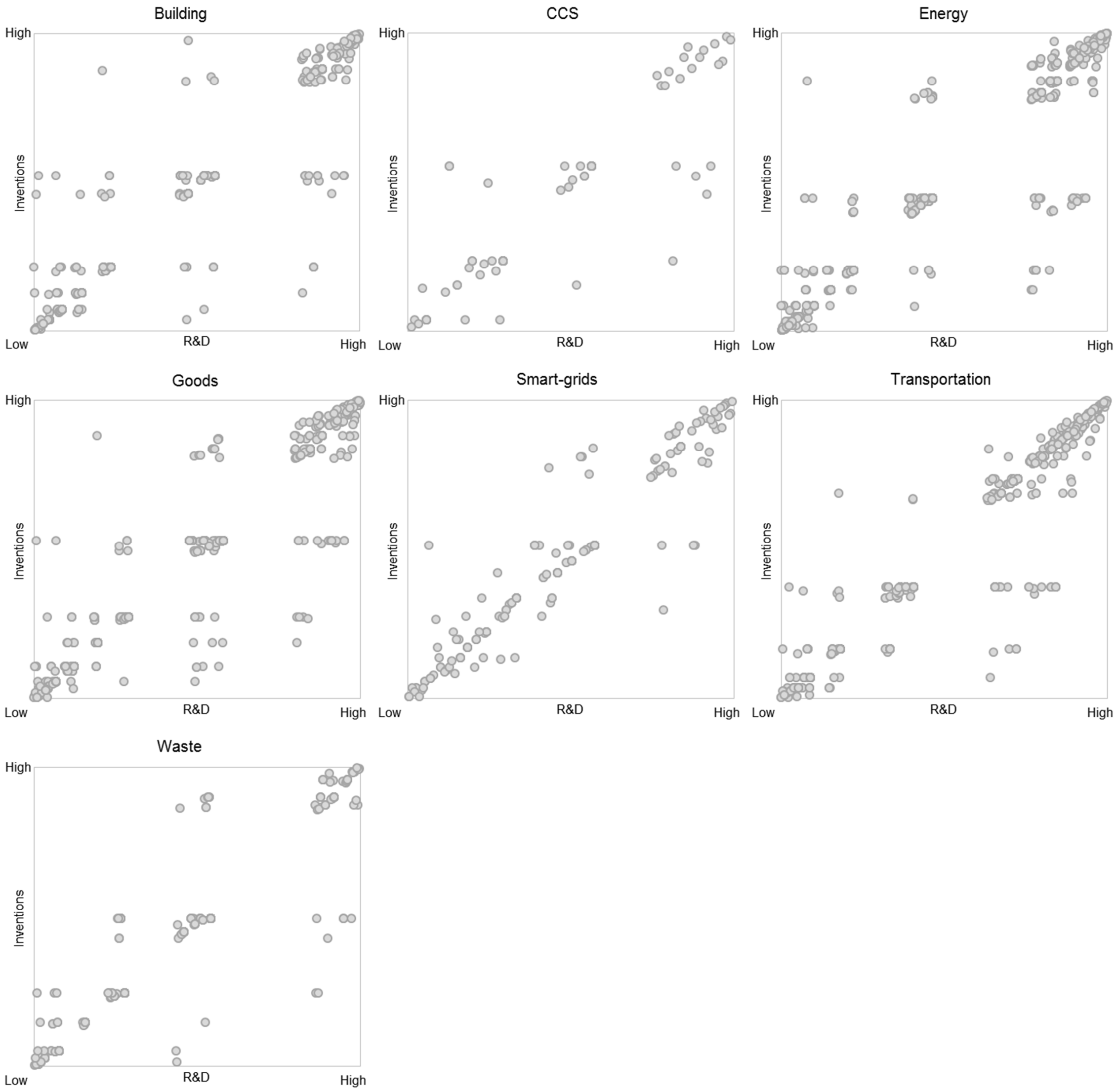

Fig. 14 Scatter plots per technology area, in 2012: company heterogeneity

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