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STATE-OF-THE-ART

A critical review of empirical research on open innovation adoption

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Abstract The open innovation approach has been one of the most discussed topics in innovation management literature in the 2000s. Over the past few years, academic publications on open innovation have increased substantially. This paper attempts to summarize and review the state-of-the-art of empirical open innovation research and develop new opportunities for open innovation research in the future. In order to make the papers more comparable, a clear focus on large-scale quantitative-oriented studies was set. From a total of 282 documents, 30 studies were analyzed in detail along four key dimensions: Firstly, different methods of measuring open innovation adoption are compared. Then, the level of open innovation adoption is analyzed on a general basis. Thirdly, the level of adoption is compared at the level of the open innovation mode (inbound and outbound). Finally, the study results regarding the variables that influence open innovation adoption are compared and conclusions for future research directions are drawn.

Keywords Open innovation · State-of-the-art · Literature review · Adoption · Drivers · Characteristics · Empirical research

JEL Classification D22 · M1 · O32

Zusammenfassung Open Innovation ist einer der meist diskutierten Ansätze in der Innovationsmanagementliteratur der 2000er Jahre. Speziell in den letzten Jahren sind wissenschaftliche Veröffentlichungen zu Open Innovation stark angestiegen. Der Artikel fasst empirische Veröffentlichungen zum Stand der Wissenschaft im Sinne eines

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State-of-the-Art-Reviews zusammen und entwickelt Ansätze für zukünftige empirische Forschung zum diesem Thema. Um die zu untersuchenden Studien vergleichbarer zu machen, wurden explizit quantitativ orientierte Studien ausgewählt. Von einer Gesamtzahl von 282 Dokumenten wurden schlussendlich 30 Studien in vier Dimensionen detailliert analysiert: Zunächst werden Messmethoden von Open Innovation Adoption verglichen. Weiters wird der allgemeine Level der Open Innovation Adoption analysiert und verglichen sowie das Adoption-Niveau auf Open Innovation Mode Level (Inbound und Outbound) analysiert. Abschließend werden das Adoptionsniveau beeinflussende Faktoren verglichen und es werden Schlussfolgerungen für zukünftige Forschung gezogen.

Schlüsselwörter Open Innovation · Review · Adoption · Einflussfaktoren · Charakteristika · Empirische Forschung

1 Introduction

The open innovation approach (Chesbrough 2003, 2006a, 2011) describes itself as the new paradigm in modern innovation management and has been one of the most discussed topics in innovation management literature in the 2000s (cf. Huizingh 2011). Open innovation enables companies to open their innovation processes in order to integrate external know-how (outside-in process) as well as utilize internal knowledge in external markets (inside-out process). In contrast to the vertical integrated innovation model (Chandler 1977, 1990), where all knowledge is internalized and controlled by the firm, the open innovation paradigm (Chesbrough 2003, 2006a) can be characterized by its porous innovation process and the strong interaction between the company and its environment. The target of open innovation is both the integration of external sources of innovation into the company and the identification of external paths for commercializing internally sourced innovations (West and Bogers 2010). The basic assumption of the concept is that both are profitable for the firm (West and Bogers 2010).

The concept of open innovation is one of great universality, which may be one reason why practitioners and academics have often failed to stick with the initial definition by Chesbrough (2006b) and used the term in other contexts. However, in this article we will stick with the original definition: "Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. This paradigm assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology" (Chesbrough 2006b).

Over the last few years, open innovation has become an important element of firms' innovation processes in almost every industry (Chesbrough and Crowther 2006; OECD 2008; De Backer et al. 2008; Chesbrough 2011). As open innovation became popular in practice, the scientific community too started investigating the concept, first theoretically (Chesbrough 2003; Gassmann and Enkel 2004; Chesbrough 2007), then with qualitative case studies (e.g. Kirschbaum 2005; Fetterhoff and Voelkel 2006; Dittrich and Duysters 2007; Bröring and Herzog 2008;

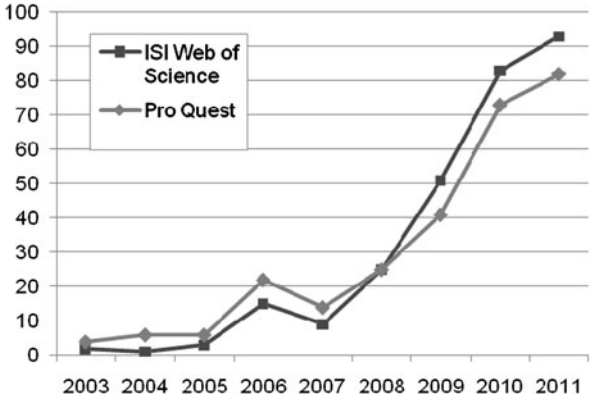

Fig. 1 Number of published articles in scholarly journals on 'open innovation'

Rohrbeck et al. 2009) and in recent years through large-scale quantitative empirical work (Laursen and Salter 2006; van der Meer 2007; Lichtenthaler 2008).

As a result, the number of academic publications on open innovation has increased substantially over the past few years. In March 2012, we conducted research using two popular scientific databases and found a total of 273 articles on the subject in the ABI/INFORM Global database (Pro Quest) and 282 in the ISI Web of Science (these were peer-reviewed articles with 'open innovation' in the title or abstract). Figure 1 shows that the number of articles has increased tremendously in 2009 and 2010. In 2011, the number of published articles grew once more, but at a lower rate. Depending on the source, up to 62 % of the total publication output to date was published in 2010 and 2011.

Based on the growing number of studies, the aim of this article is to summarize the state-of-the-art of open innovation research and provide transparency regarding the current state of the literature. The paper focuses on quantitative-oriented open innovation research, especially studies on the adoption of open innovation activities in firms. Our goal is to summarize and structure the existing research, to compare and analyze the research methods and findings, and finally to develop suggestions for future quantitative studies. By analyzing selected publications along four key dimensions, we provide future researchers with an analysis of the research papers in the field and a basis for designing quantitative-oriented open innovation studies.

Although other review articles exist, none of them focuses solely on quantitative research. Elmquist et al. (2009) studied 39 open innovation publications published up to November 2007 and identified seven streams of theoretical open innovation research: the notion of open innovation, business models, organizational design and boundaries of the firm, leadership and culture, tools and technologies, intellectual property, and industrial dynamics and manufacturing. Dahlander and Gann (2010) reviewed 140 papers published up to August 2009. They analyzed who has been working with whom and then categorized the existing literature into two dimensions: inbound versus outbound and pecuniary versus non-pecuniary. Lichtenthaler (2011) identified four streams of open innovation research: technology transactions, user innovation, business models, and innovation markets. Furthermore, he summarized the literature on the characteristics and drivers of open innovation, namely, firm-level capabilities like inventive capacity and absorptive capacity, project-level decisions

and individual-level attitudes. Other review articles are mostly editorials for special issues, for example Huizingh (2011) and van de Vrande et al. (2010). van de Vrande et al. (2010) found 88 articles on open innovation published between 2004 and 2008, of which 55 had an empirical focus.

Contrary to the existing review articles, the aim of the current article is to take a closer look at quantitative empirical open innovation research. These broad empirical studies are increasingly being requested by the scientific community (e.g. Gassmann and Enkel 2004; Fredberg et al. 2008; De Backer et al. 2008) to empirically confirm prior qualitative studies and theoretical papers. However, quantitative-oriented studies have not been compared in a structured state-of-the-art review. This is the purpose of the current paper.

As we will show in the remainder of the paper, the existing literature is quite diverse regarding definitions and research methodologies. Therefore, aggregation and statistical analysis in the form of a meta-study is not possible. Instead, we opt for the more qualitative approach of a state-of-the-art literature review.

We select research questions that are already mentioned by several authors, which enables a comparison between papers. To do so, we mainly focus on the contingency perspective: When a new concept like 'open innovation' is introduced its validity has to be proved (Elmquist et al. 2009). Therefore, empirical literature must prove that open innovation exists in practice, and in what form. We distinguish in our study between the general openness of a firm, as a one-dimensional construct, and a more detailed perspective based on a number of open innovation activities that are part of the open innovation continuum (two- or multi-dimensional approach), with inbound and outbound open innovation being its two basic forms.

The most basic research question that the empirical literature could answer would be the existence of open innovation in practice: To what extent is open innovation generally used by firms? For this purpose, open innovation is defined as a one-dimensional construct (open versus closed). However, from the multi-dimensional perspective, the question becomes: What form of open innovation is used? Are certain open innovation modes (inbound/outbound) or specific open innovation activities (e.g. customers) used more than others?

With knowledge about the existence of open innovation adoption rates, the next question typically answered by studies is: Why are companies using open innovation? This leads to the drivers and determinants of the phenomenon. By comparing differences in adoption rates between different industries, different countries or different open innovation activities, the drivers of openness can be examined (cf. Huizingh 2011; Elmquist et al. 2009). Additionally, this paper will focus on methodology and compare how the selected studies were designed in this regard. How were the data collected and what measurement scales were used for open innovation adoption? As we are comparing the findings of quantitative studies, it is especially important that we understand the underlying empirical setting.

These questions build the structure for Sects. 3 to 6, in which the contents of the identified articles are analyzed and compared. The rest of the paper is structured as follows: The next section outlines the literature review method. Sections 3 to 6, to be more specific, evaluate and compare the papers along four dimensions: the measurement of open innovation adoption (the methodologies of the selected studies), the

level of adoption of open innovation (one-dimensional construct), the usage of open innovation modes (two- or multi-dimensional construct), and influencing factors (determinants). The last section draws conclusions about the findings and presents suggestions for future research.

2 Literature review method

The bibliometric search was intended to cover studies on open innovation adoption published between 2003 and February 2012. Our first step was to conduct a database search using the search term 'open innovation'. We used the ISI Web of Science database and selected articles that had 'open innovation' in the title, keywords or abstract. As the ProQuest database contains more articles on open innovation than the ISI database, the search was rerun in the ProQuest database in order to find additional articles. We used just the very narrow search term of 'open innovation' so as to only include papers that refer directly to the open innovation approach. Similarly, the timeframe was restricted to articles published from 2003 onwards, as the term 'open innovation' was originally coined in 2003. Our second step consisted of reading the articles and following footnotes and references to other articles. This led to the inclusion of working papers, dissertations, and NGO publications. In our third step, we searched for studies with the keyword 'distributed innovation', which is a synonym for 'open innovation'.

Based on the aim of this state-of-the-art review, a set of four criteria was developed in order to select a limited number of comparable studies which would enable us to answer our research questions.

The articles finally selected had to meet the following criteria:

2.1 Definition of open innovation

As open innovation is not a clear-cut concept, it can come in many forms (Huizingh 2011) and the definitions used might be substantially different from our definition of open innovation. In our understanding, open innovation encompasses various inbound and outbound activities, as defined by Gassmann and Enkel (2004) and Chesbrough (2003, 2006a). Therefore we only selected studies that cover all or a substantial proportion of these activities, and do not focus on special subjects such as user innovation or open source. For each study, we analyzed how the term 'open innovation' was used in the article and whether it corresponded to our definition of open innovation.

2.2 Quantitative-oriented empirical studies

Case studies are an important method of advancing research, but large-scale studies are the only reliable option if we wish to validate propositions and theories empirically. Therefore, 'success stories' based on single organizations had to be excluded, as these single-firm case studies cannot be generalized. Following this logic, multiple-firm case studies with only a small number of cases were also excluded (e.g. Gassmann and Enkel 2004; Chesbrough and Crowther 2006; Chiaroni et al. 2010; Bianchi et al. 2011), as such studies do not provide comparable quantitative data.

2.3 Firm focus

Open innovation was originally introduced as a firm-level concept. van de Vrande et al. (2010) mentioned that 50 % of the empirical papers in their sample took the firm as their unit of analysis. Therefore, it makes sense for us to focus on this area, which is by far the most extensively covered, in order to ensure that our studies are more easily comparable with each other. Inventors, individuals, innovation projects, innovation intermediaries, geographical regions or industries are not within scope of this article.

2.4 Adoption of open innovation

Our research questions focus on already-established research streams in the open innovation literature, which again allows us to more easily make a direct comparison between the papers. One of the most popular streams in empirical open innovation research is the diffusion of open innovation, which includes themes such as the general level of open innovation adoption, the adoption level for single open innovation modes and the influencing and moderating factors on firms' adoption decisions.

In the first step, we identified 282 documents in scholarly journals. Papers that fulfilled the search criteria were analyzed. Several duplicates (e.g. dissertations or government reports that were later published in journals) were excluded. In total we identified 30 relevant papers within the scope of our analysis. Table 1 presents an overview of the selected studies.

3 Measurement of open innovation adoption

Empirical open innovation research is often only slightly comparable with other works of that type, as the studies use a variety of definitions of open innovation. Also, because open innovation is a construct that cannot be measured directly, methodologies can differ widely. Measurement of open innovation adoption requires measuring individual adoption activities and measuring the level of each activity is complicated because they are often diffusely organized within a firm and organized very differently in different firms. Because of resource constraints, studies are therefore usually limited to subjective measurement scales.

Despite these complications, academic research has developed scales to measure the level of open innovation adoption. This section aims to compare these measurement approaches and the data sources used, as this is the basis for understanding the results presented in Sects. 4 to 6. In Table 2 the data collection of several large-scale studies is compared.

3.1 Scales for open innovation adoption

Based on the data from the Community Innovation Survey (CIS), Laursen and Salter (2006) first introduced the concept of external search breadth and depth to measure the level of open innovation adoption. Breadth is defined as the number of external sources or search channels that firms use for their innovative activities. External

Table 1 Overview of (selected) large-scale empirical open innovation research

Study	Topic/Focus
Acha (2008)	Role and influence of "design" as a determinant of open innovation adoption
Barge-Gil (2010)	Open innovation adoption and its determinants in Spanish firms
Batterink (2009)	Longitudinal quantitative analysis of the open innovation adoption behaviors of Dutch firms
Belussi et al. (2010)	Open innovation adoption outside the boundaries of the region (Open Regional Innovation System)
Chen et al. (2011)	Study of Chinese firms and how their innovative performance is affected by the scope, depth, and orientation of their external search strategies
Chiang and Hung (2010)	Effect of open search depth and breadth on innovation performance in Taiwan
Chiaroni et al. (2009)	Adoption of open innovation in the bio-pharmaceutical industry; empirical study of top 20 pharmaceutical firms worldwide
De Backer et al. (2008)	Systematic presentation of descriptive statistics on the status of open innovation; use of several secondary data sources
Drechsler and Natter (2008)	Linking open innovation activities to innovation and business performance and identifying antecedents and drivers of open innovation; cross-sectional study
Faems et al. (2010)	Studying the effect of open innovation in the form of technology alliances on innovation performance
Filippetti (2011)	Study using data from the Innobarometer 2009 on the adoption-influencing factors of R&D and design
Huang (2011)	Study on the ability of open innovation to moderate intra-organizational learning mechanisms and technological innovation capability
Ili et al. (2010)	Study on the productivity of open innovation in the German automotive industry
Inauen and Schenker-Wicki (2011)	Study in German-speaking countries on the influence of outside-in open innovation on innovation performance
Laursen and Salter (2006)	First quantitative study using CIS data, focusing on the relationship between the openness of firms and their innovation performance
Lazzarotti et al. (2010)	Open innovation adoption in Italian manufacturing companies; cluster analysis by partner variety and innovation phase variety
Lazzarotti et al. (2011)	Study of firm-specific factors that influence open innovation adoption in Italian firms
Lee et al. (2010)	Open innovation adoption strategies in Korean SMEs
Lichtenthaler (2008)	Identification of groups of firms pursuing homogeneous open innovation strategies, regarding external technology acquisition and external technology exploitation

Table 1 (*Continued*)

Study	Topic/Focus
Lichtenthaler (2009)	Relationship between outbound open innovation and firm performance under different environmental settings
Lichtenthaler (2010)	Role of corporate patent portfolio in open innovation adoption
Lichtenthaler and Ernst (2008)	Performance of innovation intermediaries; case study approach with 35 interviews in 25 firms
Lichtenthaler and Ernst (2009)	Role of technology aggressiveness as a major determinant of open innovation; form and level of open innovation adoption
Mention (2011)	Influence of cooperation and the use of external and internal sources of innovation on the degree of innovation novelty
Podmetina and Väätänen (2011)	Study of R&D-oriented Russian companies and their degree of technology acquisition and technology commercialization
Schroll and Mild (2011a)	Status of open innovation adoption at a European level and the role of R&D intensity
Schroll and Mild (2011b)	Determinants of open innovation adoption: organizational capabilities, characteristics of the industry and human drivers
Schweitzer et al. (2011)	Effect of turbulent environment on open innovation adoption
van de Vrande et al. (2009a)	Focus on level of adoption, motives, barriers of open innovation in Dutch SMEs
van der Meer (2007)	Adoption of open innovation principles (culture and mechanisms) by Dutch companies

search depth is the extent to which firms draw from these external sources. While external search breadth is a binomial scale (0 for not used, 1 for used) with 16 items (= sources), external search depth is measured on a four-point scale (from 0 to 3), but only high usage (3) is counted as a deep use of the source.

This scale has been used by several researchers. Chiang and Hung (2010) followed the definition of Laursen and Salter (2006) to measure the extent of open search adoption by Taiwanese electronic product manufacturers. They also used a 0–3 scale for measuring the degree of importance of 16 pre-defined sources. In a comparable approach, Belussi et al. (2010) evaluated degree of openness by rating the importance of 16 potential sources (market-based, institutional, semi-public) on a ten-point scale. External search breadth was measured similarly to Laursen and Salter (2006). Additionally, the number of external collaborative relationships was measured to assess the impact of external sources on the firm's innovation capability. Acha (2008) operationalized the degree of openness using seven measures from the UK Innovation Survey, using the same scale as Laursen and Salter (2006), but only listing 11 potential external information sources. Faems et al. (2009) measured the diversity of technology alliance portfolios by the engagement in interorganizational agreements involving innovation. Also, Lee et al. (2010) used breadth and depth as indicators for open innovation usage. Similarly to Laursen and Salter (2006), they added up 17 binary variables (16 external, 1 within the firm) to measure breadth and depth. Filippetti (2011) used data from the Innobarometer Survey 2009, which included a

specific question about design as a source of innovation. However, as the scales in that survey are not compatible with other open innovation scales (such as those in the CIS), no comparison of results is possible.

While scales based on Laursen and Salter (2006) were usually used in studies using existing data sources (e.g. CIS), five studies have adapted their scales for studies with own data collection: Chen et al. (2011) measured the degree of openness in a similar way to Laursen and Salter (2006), using a two-dimensional approach of search breadth (diversity) and depth with 10 indicators. Schweitzer et al. (2011) used the scales provided by Laursen and Salter (2006). A similar approach was used by Schroll and Mild (2011a, 2011b), who measured adoption with a total of 16 indicators on seven-point Likert scales.

Other studies using their own data collection have usually used individual scales to measure adoption. Lichtenthaler (2009) used a four-item seven-point scale to measure the existence of outbound open innovation strategies. Contrary to other studies, Lichtenthaler (2009) did not ask respondents about the extent of specific open innovation activities (e.g. licensing, patents) but the general use of external technology commercialization and its restrictions. Lichtenthaler (2008) and Lichtenthaler and Ernst (2009) used subjective measures to operationalize the constructs of external technology acquisition and external technology exploitation as indicators of open innovation adoption on seven-point Likert-type scales.

Barge-Gil (2010) used a different approach to measure the openness of a company, measuring two forms of open innovation in a way that eliminates individual bias. First, the form of innovation development (internal, collaboration, third parties) is measured. Then, the subjective importance of the different sources is measured on a four-point scale. This operationalization measures the openness of a firm in its 'own relative terms' (Barge-Gil 2010).

van de Vrande et al. (2009a) measured the extent of open innovation only for each activity individually and not using a general scale for overall open innovation. For instance, for customer involvement, they used a binary scale for several questions regarding the integration of the customer. Their open innovation construct included licensing activities and venturing on the outbound side and customer involvement, employee involvement, network usage, participation in other firms, outsourcing R&D and licensing activities on the inbound side.

Huang (2011) measured open innovation with a set of three indicators focusing on (i) external licensing; (ii) engagement in collaborative activities; (iii) own licensing activities. Each indicator was measured on a five-point Likert scale ranging from 5 ('strongly agree') to 1 ('strongly disagree'). Inauen and Schenker-Wicki (2011) used a five-year reference period from 2004 to 2008 to measure the intensity of open innovation activities. Their open innovation construct was based on the Oslo manual, included seven indicators and was measured on a five-point Likert scale. Also, Lazzarotti et al. (2011) used a seven-item scale for their construct of 'partner variety within the last 5 years', but on a four-point Likert scale.

3.2 Data collection

The CIS has been the basis for the majority of large-scale empirical studies on open innovation. Laursen and Salter (2006) based their study on the CIS-based UK Inno-

vation Survey, which contained a sample of 2,707 manufacturing firms. In a similar approach, Acha (2008) used the UK Innovation Survey database from 2005 (CIS-4), which includes a sample of 16,445 firms from the years 2002 to 2004. Mention (2011) used data from the Luxembourgish CIS-4 (2002–2004). Their sample included 1,052 service firms from the Luxembourgish service sector, with 30 % of the firms belonging to the financial sector. van der Meer (2007) used the 814 responses from the Dutch National Innovation Survey and additionally carried out 28 in-depth interviews. Also, Batterink (2009) based his quantitative analysis on longitudinal CIS data from the Netherlands. Faems et al. (2010) tested their model with a sample of 323 Belgian manufacturing firms, based on the fourth CIS and the Belfirst database. De Backer et al. (2008) used data from the CIS-4 to test the extent of open innovation at the European level. Finally, Filippetti (2011) derived his data from the Innobarometer Survey 2009 using a large Europe-wide sample collected between 2006 and 2008.

van de Vrande et al. (2009a) used a dataset that was collected by EIM, a research institute in the Netherlands. Respondents were contacted by telephone and were mostly small business owners, managers or innovation decision makers. Lichtenthaler and Ernst (2008) conducted 35 unstructured interviews in 25 European industrial firms. Additionally, a survey with 155 participants was conducted in collaboration with the Licensing Executives Society (LES) in Germany, Switzerland and Austria. The results were also used by Lichtenthaler and Ernst (2009) and Lichtenthaler (2009). Drechsler and Natter (2008) studied a sample of 240 German firms while Schroll and Mild (2011a, 2011b) collected data on 180 companies in 24 European countries. Schweitzer et al. (2011) used a sample of 103 companies from the plastics and wood industry in Austria. Chiaroni et al. (2009) selected the top 20 pharmaceutical biotech firms worldwide and collected data on the usage and typology of open innovation.

Ili et al. (2010) conducted a study in the German automotive industry, comprising 42 companies. Based on the results of the questionnaire, a semi-structured interview was then conducted. Chiang and Hung (2010) surveyed randomly selected Taiwanese electronic product manufacturing companies. A total of 220 responses were collected in the first phase in 2007. One year later, another questionnaire was sent out, yielding 184 effective responses. Barge-Gil (2010) used data from an innovation panel in the Spanish Institute of Statistics (PITEC). Lazzarotti et al. (2010) studied 99 manufacturing companies belonging to the Northern Italian region of Lombardia. Belussi et al. (2010) studied life science companies in the Italian region of Emilia Romagna.

Chen et al. (2011) gathered 209 questionnaires from the R&D centers of companies with a national or provincial R&D center in Zhejiang, China. Huang (2011) used a combined approach of questionnaires, and a telephone survey as a supplementary tool to increase the response rate. This approach was also used by Inauen and Schenker-Wicki (2011), who restricted their sample to stock-listed companies in Germany (CDAX), Switzerland (SPI) and Austria (WBI). Banks and insurance companies were excluded as they were unable to provide full information on all the required innovation measures. Podmetina and Väätänen (2011) relied completely on face-to-face structured interviews with 158 Russian companies.

In general, most studies have focused on either a single country or a single industry. Interestingly, empirical research focuses mostly on adoption in Europe, and to

a slight extent also in Asia, but studies from other continents are still missing. This may also be a result of the availability of the CIS, which has had a big influence on open innovation research. Future research may rely more on primary data collection. This trend is already visible: Earlier publications (2006–2009) mostly used secondary datasets (7 out of 12, with 4 of the remaining studies using primary data from one data collection process by Lichtenthaler), while the recent publications (2010–2011) mostly used primary data (11 out of 15).

While studies using secondary data usually have sample sizes of at least 300 (ranging up to 16,000), studies using primary data collection typically have sample sizes of between 100 and 200. As a result of these still relatively high sample sizes, the data are only collected via questionnaires. As shown earlier, the questionnaires usually use subjective scales: CIS-type scales measure breadth and depth on binary or four-point subjective scales (yes/no; low extent/high extent). The same is true for studies using their own data collection process, such as Lichtenthaler (2008, 2009, 2010) or Schroll and Mild (2011a, 2011b). The universal open innovation scale introduced by Laursen and Salter (2006) has become almost standard in many current studies; however, current studies are now using a seven-point Likert scale instead of a binary scale. While Barge-Gil (2010) used an alternative scale which set the innovation activity in relation to its importance, it was still a subjective scale. Future research could address this potential bias by relying on objective scales, such as the number of external partners involved or the number of patents/licenses bought and sold.

4 Adoption of open innovation

Since empirical work on open innovation was initially mainly based on case studies or project experiences in single firms, the first quantitative empirical studies often focused on the question of whether the theoretical concept of open innovation was used by firms and if so to what extent. This section presents and compares these studies regarding the level of open innovation adoption found.

Drechsler and Natter (2008) found that 76 % of the companies they examined had adopted open innovation, in the sense that they were involved in both inbound and outbound activities. They found that the adoption of open innovation had a positive influence on a firm's business performance. A common approach used is to cluster the sample according to the level of open innovation used. Schroll and Mild (2011a) conducted a cluster analysis and then used a concept introduced by West and Bogers (2010) to distinguish between four different groups of innovators. Their results showed that inbound cooperation activities (4.03 on a seven-point Likert scale) are used significantly more than acquisition (2.98) or outbound activities (2.92). For the overall open innovation construct, an average adoption level of 3.55 was found.

Van de Vrande et al. (2009a) measured practices used for open innovation, such as venturing, licensing or customer involvement. They identified three types of firms, in terms of open innovation adoption, among Dutch SMEs: 10 % of the sample did not adopt open innovation, 68 % were characterized as medium adopters and 22 % as strong adopters. However, their study did not provide a real scale for adoption, only activity levels were measured. A similar approach was used by Barge-Gil (2010),

Table 2 Comparison of data collection

Study	Method/source	Sample size	Sector/industry country	Data collection and year
Laursen and Salter (2006)	Questionnaire	2,707	Manufacturing United Kingdom	CIS (UK Innovation Survey)
Acha (2008)	Questionnaire	16,445	United Kingdom	CIS-4 (UK Innovation Survey) 2002–2004
Mention (2011)	Questionnaire	1,052	Service sector Luxembourg	CIS-4 2002–2004
van der Meer (2007)	Questionnaire In-depth interviews	814	All sectors Netherlands	Dutch National Innovation Survey database 2004
Batterink (2009)	Questionnaire	–	Manufacturing Netherlands	CIS 1994–2004
De Backer et al. (2008)	Questionnaire	–	26 European countries	CIS-4 (or nearest available year) 2002–2004
van de Vrande et al. (2009a)	Telephone interviews	605	All sectors, but only SMEs (up to 500 employees) Netherlands	EIM database 2005
Faems et al. (2010)	Questionnaire	323	Manufacturing Belgium	CIS-4 2002–2004
Filippetti (2011)	Questionnaire	5,238	27 EU Members plus Switzerland and Norway	Innobarometer Survey 2009
Lichtenthaler (2008, 2009, 2010) Lichtenthaler and Ernst (2009)	Questionnaire	155	Manufacturing Germany, Switzerland and Austria	Own data collection, in collaboration with LES 2004
Lichtenthaler and Ernst (2008)	In-depth interviews	35 interviews, 25 firms	Manufacturing Germany, Switzerland	Own data collection

Table 2 (*Continued*)

Study	Method/source	Sample size	Sector/industry country	Data collection and year
Drechsler and Natter (2008)	Questionnaire	240	All industries (including service sector) Germany	Own data collection 2007
Schroll and Mild (2011a, 2011b)	Questionnaire	180	All industries (including service sector) 24 European countries	Own data collection 2009
Schweitzer et al. (2011)	Questionnaire	103	Plastics and wood industry Austria	Own data collection
Ili et al. (2010)	Questionnaire In-depth interviews	42	Automotive Germany	Own data collection
Chiaroni et al. (2009)	Annual reports	20	Pharmaceutical biotech firms	Annual reports from 2000–2005
Chiang and Hung (2010)	Questionnaire	184	Electronic product manufacturers Taiwan	Own data collection (2007 and 2008)
Barge-Gil (2010)	Questionnaire	10,875	Manufacturing industries Spain	Spanish Institute of Statistics (PITEC) 2004–2006
Lazzarotti et al. (2010, 2011)	Questionnaire	99	Manufacturing Italy	Own data collection
Belussi et al. (2010)	Semi-structured interviews	78	Life science industry Italy	Own data collection 2005
Chen et al. (2011)	Questionnaire	209	No industry focus China	Own data collection 2006–2007
Huang (2011)	Questionnaire Telephone survey	328	Biotechnology firms Taiwan	Own data collection 2009
Inauen and Schenker-Wicki (2011)	Questionnaire Telephone survey	141	Stock-listed companies Germany, Switzerland, Austria	Own data collection 2004–2008
Podmetina and Väätänen (2011)	Structured interviews	158	All industries Russia	Own data collection 2008

who described three types of firms according to the way they developed innovations: 20.6 % were open innovators, 34.8 % semi-open innovators, and 44.5 % closed innovators. Another scale measured openness by the subjective importance of these external sources of innovation. According to this scale, 22.6 % of the sample was found to be open innovators, 51.6 % semi-open innovators and 25.8 % closed innovators.

Lazzarotti et al. (2010, 2011) also clustered their responses, this time by partner variety and phase variety. Through this approach, they identified 43 % of their sample as open innovators. Belussi et al. (2010) found that 58 % of their sample were involved in external research collaborations and that, on average, the firms used 4.7 out of the 16 possible external sources of innovation.

Podmetina and Väätänen (2011) grouped their results in a two-dimensional matrix with the degree of outbound open innovation (technology commercialization) on one axis and the degree of inbound open innovation (technology acquisition) on the other. They found that 46.9 % of the sample belonged to clusters which could be described as open. Their results are comparable to the 2 × 2 matrix produced by Schroll and Mild (2011a), with the vast majority of companies adopting the inbound mode more than the outbound mode.

Three other studies (with a specific industry focus) also clustered their samples into groups: Lichtenthaler and Ernst (2009) identified six clusters of open innovation adoption in medium-sized and large firms: 18.2 % were using inbound activities to a limited extent and 29.2 % had opened up in at least one direction. However, these numbers should be interpreted carefully, as Lichtenthaler and Ernst (2009) described their sample as not representative of all firms and therefore it might not be possible to draw a general conclusion. With the same set of data, Lichtenthaler (2008) identified six clusters of firms. Two clusters were characterized as "closed innovators", comprising 67.5 % of the sample. However, these two studies are not directly comparable, as Lichtenthaler and Ernst (2009) included the degree of technology aggressiveness in their cluster analysis, while Lichtenthaler (2008) did not.

Despite some prime examples such as DSM or Philips, van der Meer (2007) describes Dutch firms as reluctant to take part in open innovation adoption. Of 28 firms who declared themselves as highly innovative, 68 % showed cultural characteristics of open innovation. If adoption was measured by the use of importing mechanisms, 74 % were identified as open innovation adopters, while if measured by the use of exporting mechanisms, the figure was 54 %.

In order to conclude, Table 3 compares the results of selected studies using cluster analysis. It should be taken with caution, in that most of the studies are not directly comparable with each other because they use different samples, different adoption scales or different statistical procedures. Therefore, the percentage of companies strongly adopting open innovation (open innovators) and that using it to a medium degree vary wildly. However, it can be noted that, in recent studies, the portion of companies not using open innovation is relatively small, while older studies tended to find a larger portion of "closed companies":

Lichtenthaler and Ernst (2009) and Lichtenthaler (2008) found 52.6 % and 67.5 % to be closed innovators out of their sample collected in 2004. Barge-Gil (2010) found 44.5 % closed innovators in his sample from 2004–2006. In 2009, Schroll and Mild (2011a) found only 31 % of their sample to be closed innovators. Meanwhile, van de

Table 3 Open innovation adoption clusters

Study	Sample	Adoption clusters in %
Drechsler and Natter (2008)	240 firms; 2007; All industries; Germany, Austria, Switzerland	76 % adopted open innovation
Schroll and Mild (2011a)	180 firms; 2009; All industries; 24 European countries	31.0 % closed innovators 37.7 % semi-open innovators 30.3 % open innovators
Barge-Gil (2010)	10,875 firms; 2004–2006; Manufacturing industries; Spain	44.5 % closed innovators 34.8 % semi-open innovators 20.6 % open innovators
van de Vrande et al. (2009a)	605 SMEs; 2005; All sectors; Netherlands	10 % not adopted 68 % medium adopters 22 % strong adopters
Lazzarotti et al. (2010)	99 firms; Manufacturing industries; Italy	36 % closed innovators 9 % integrated collaborators 11 % specialized collaborators 43 % open innovators
Lichtenthaler and Ernst (2009)	155 firms; 2004; Manufacturing; Germany, Austria, Switzerland	52.6 % closed innovators 18.18 % opened up to limited extent in technology exploration 29.22 % opened up, at least in one direction
Lichtenthaler (2008)	155 firms; 2004; Manufacturing; Germany, Austria, Switzerland	67.5 % closed innovators 9.1 % absorbing innovators 8.4 % balanced innovators 6.5 % distributing innovators 8.4 % open innovators

Vrande et al. (2009a) found 68 % to be 'medium adopters' and Lazzarotti et al. (2010) described 43 % of their sample as open innovators. Although there is still a high degree of variation and the studies are not directly comparable, these results could indicate an increasing level of open innovation adoption.

Future studies will need to agree on a common understanding and definition of adoption clusters. The term 'closed innovators', for firms using a vertically integrated innovation model, is already used by most studies. However, while some studies (van de Vrande et al. 2009a; Schroll and Mild 2011a) then distinguish between medium and high adopters (semi-open and open innovators), others such as Lichtenthaler (2008) and Lazzarotti et al. (2010) cluster based on the form of open innovation (collaborators, absorbing innovators, ...). Currently, the methodologies used for deriving these adoption clusters are different for each study, as well as the definitions.

5 Usage of open innovation modes

Open innovation is a multi-dimensional construct, based on a number of open innovation activities. However, in a simplified form, open innovation can be thought of as a two-dimensional construct, as firms can open up their innovation process along two dimensions: inbound and outbound (Lichtenthaler 2009; West and Bogers 2010). As processes tend to be fundamentally different from each other, firms may prefer to focus on just a single process. In this section, we will compare open innovation adoption at this detailed level.

5.1 Adoption measured by breadth and depth

Laursen and Salter (2006) were the first to use the concepts of search breadth and depth to measure the level of open innovation adoption. However, they focused on external sources of innovation, and did not cover technology exploitation. Their results show an inverted U-shaped relation between innovative performance and the number of different sources used. According to Laursen and Salter (2006), the optimal number of external sources is 11; if firms use more sources, there might be negative returns. This inverted U-shaped relationship between the breadth of external sources used and innovation performance was also found by Drechsler and Natter (2008). However, they found that using four out of the seven external sources studied was the optimum. Their results also showed that outbound activities are significantly less well used than inbound activities—in terms of both breadth and depth of adoption (see Table 4). Using the scale developed by Laursen and Salter (2006), Schweitzer et al. (2011) find a high degree of search breadth in their sample (10.73 on a 16-point scale).

Lichtenthaler (2008) and Lichtenthaler and Ernst (2009) again found that the extent of inbound acquisition activities was greater than the extent of outbound activities, but that both occurred at a low level (2.81 and 2.40 on a 7-point scale). In line with the expectation that technology exploitation is less well adopted than technology exploration, Lichtenthaler and Ernst (2009) discovered that, with the adoption of inbound activities, the barrier to adopting outbound activities becomes lower. Similarly, Schroll and Mild (2011a) identified two patterns in their data: First, if a company adopts inbound open innovation, it is also more likely to adopt outbound methods. Secondly, companies currently adopt more inbound methods than outbound methods: 85.6 % of their sample used more inbound methods than outbound. In terms of open innovation activities, cooperation with customers is widespread (5.54 on a 7-point scale), but cooperation with suppliers (4.55), lead users (4.56), universities (4.44) and R&D institutes (4.20) is also fairly common (for details refer to Table 4). This is in line with Inauen and Schenker-Wicki (2011), who also found collaboration with customers (2.99 on a 5-point Likert scale), suppliers (2.22), and universities (2.095) to be widespread. In the Chinese sample used by Chen et al. (2011), competitors and the government were also found to be used to a high extent (4.2 and 4.1 on a 7-point scale).

Lichtenthaler (2009) focused on outbound open innovation and found a positive effect on a firm's business performance. However, because of the exclusive focus on

outbound activities, the single measure of outbound activities (4.14) cannot be set in relation to other measures. The same is true of Faems et al. (2010), who found the diversity in technology alliance portfolios to be 1.89 on a 6-point scale.

5.2 Adoption measured by adoption clusters

While some studies measure adoption behaviors using the concept of search breadth and depth and a seven-point Likert scale, others measure adoption of individual open innovation activities on a binary scale. This simple approach reduces the subjectivity of a seven-point Likert scale and allows for the easy comparison of adoption behaviors.

Van de Vrande et al. (2009a) used the concept of technology exploration (inbound) and technology exploitation (outbound) and found that outbound activities were used by 29 % (venturing) or 10 % (licensing) of their sample, whereas inbound activities were adopted by between 93 % and 97 %, depending on whether interaction with customers, employees, or networks was included. However, only 32 % of the sample collaborated with other firms. De Backer et al. (2008) found that companies collaborate most frequently with suppliers and customers, but less frequently with competitors and R&D laboratories. Data from the CIS-4 shows that the extent to which companies collaborate in innovation differs widely depending on the country. While in Belgium almost 60 % of large companies collaborate, in Greece and Australia only 20 % do so. When aggregating the 26 European countries, the picture becomes clearer: 69 % of the sample collaborates with suppliers and 59 % with customers. Other external sources of innovation are significantly less well used (see Table 4).

Batterink (2009) found that 30 % of small firms but over 70 % of large firms (more than 250 employees) use cooperative activities. If licensing and R&D outsourcing activities are included as well, the proportions are even higher. Chiaroni et al. (2009) found wide adoption of open innovation in the biotech industry, especially regarding inbound activities (the generation of innovations), which had increased from 57.2 % in 2000 to 67.3 % in 2005. Of the 67.3 % in 2005, 36.8 % were using collaborations, 32.9 % were purchasing scientific services and 30.3 % were in-licensing. The number of companies using outbound activities (exploitation of innovation) fell from 42.3 % in 2000 to 32.7 % in 2005. On the outbound side, companies were mostly using collaborations (56.8 %) and out-licensing (35.1 %).

Belussi et al. (2010) found an average usage of 5 external sources (out of a total of 16). In line with other studies, they found that clients and customers were the most frequently used sources and also the most relevant. Interestingly, scientific publications were the most relevant sources (9.20 on a 10-point scale), but this could be a characteristic of the life science industry studied. Ili et al. (2010) conducted a study in the German automotive industry and found that customers were seen as the most important source of innovation. The outbound side was less well used and firms were also less aware of it: Most firms for example were not aware of the potential value of their unused patents. Only one supplier in the sample of 42 companies was actively exploiting unused patents. Lee et al. (2010) analyzed the differences in the innovation processes of large firms and SMEs. Overall, they found that 59 % of their respondents

Table 4 Modes of adoption of open innovation

Study	Adoption of inbound activities[a]	Adoption of outbound activities[a]	Scale
Laursen and Salter (2006)	Breadth: 7.22 (5.30) Depth: 0.96 (1.68)	–	Breadth: Number of different external sources used (0 to 16) Depth: Number of sources used to a high degree (0 to 16)
Drechsler and Natter (2008)	Breadth: 6.20 (1.18) Depth: 4.04 (0.96)	Breadth: 1.74 (1.18) Depth: 2.37 (1.77)	Seven-point scale from 1 = 'not used', 2 = 'low use' to 7 = 'highly used'
Schweitzer et al. (2011)	Breadth: 10.73 (5.30) Depth: 3.39 (3.03)		Breadth: Number of different external sources used (0 to 16) Depth: Number of sources used to a high degree (0 to 16)
Lichtenthaler (2008) Lichtenthaler and Ernst (2009)	Breadth by acquisition: 2.81 (1.47)	2.40 (1.43)	Seven-point scale from 1 = 'strongly disagree', to 7 = 'strongly agree'
Lazzarotti et al. (2011)	Partner variety: 2.63 (0.96)		Four-point scale from 1 = 'strongly disagree', to 4 = 'strongly agree'
Schroll and Mild (2011a)	*Breadth by cooperation*: 4.03 (1.05) Suppliers: 4.55 (1.879) Clients/Customers: 5.54 (1.473) Lead users: 4.56 (2.023) Competitors: 3.30 (1.717) Consultants: 3.81 (1.631) R&D institutes: 4.20 (1.986) Universities: 4.44 (1.865) Communities: 2.88 (1.754) Opinion leaders 3.04 (1.902) *Breadth by acquisition*: 2.98 (1.57) Acquisition of patents: 2.43 (1.636) Acquisition of licenses: 3.20 (1.921) Acquisition of companies: 3.23 (1.972)	*Breadth by outbound activities*: 2.92 (1.42) Sale/divest 3.30 (2.000) Licensing out 2.87 (1.844) Financing/founding spin-offs: 2.73 (1.834) Contributing to the general public: 2.64 (1.726)	Seven-point scale from 1 = 'not used' to 7 = 'used very often'

Table 4 (*Continued*)

Study	Adoption of inbound activities[a]	Adoption of outbound activities[a]	Scale
Inauen and Schenker-Wicki (2011)	Customers: 2.990 (1.000) Suppliers: 2.220 (1.178) Competitors: 1.09 (1.043) Cross-industry firms: 1.210 (0.939) Consulting firms: 1.390 (1.082) Universities: 2.095 (1.145)		Five-point scale from 1 = 'never' to 5 = 'very often'
Chen et al. (2011)	Lead users: 4.2249 Major users: 4.5455 Suppliers: 4.1770 Competitors: 4.1675 Firms in other industries: 2.7847 Universities and research institutes: 3.6005 Technology agencies: 2.7751 Intellectual property organizations: 2.9713 Venture capital enterprises: 2.3397 Governments: 4.0574		Seven-point scale from 1 = 'low use' to 7 = 'high use'
Lichtenthaler (2009)		4.14 (1.50)	Seven-point scale from 1 = 'Strongly disagree' to 7 'Strongly agree'
van de Vrande et al. (2009a)	Customers: 97 % Employees: 93 % Networks: 94 % Other firms: 32 % Outsourcing R&D: 50 % Licensing: 20 %	Venturing 29 % Licensing: 10 %	Average open innovation practices (binary variables)

Table 4 (*Continued*)

Study	Adoption of inbound activities[a]	Adoption of outbound activities[a]	Scale
De Backer et al. (2008)	Suppliers: 69 % Customers: 59 % Competitors: 36 % Consultants and private R&D institutes: 38 % Universities and higher education: 34 % Government and public research: 25 %		Average open innovation practices (binary variables)
Batterink (2009)	Cooperation: 53 % Cooperating, licensing, or outsourcing R&D: 69 %		
Chiaroni et al. (2009)	67.3 % (2005) (generation of innovation)	32.7 % (2005) (exploitation of innovation)	
Belussi et al. (2010)	Breadth: 4.67 (3.25) (N_SOURCE) Clients and customers: 65.4 % Suppliers: 19.2 % Patent acquisitions: 10.2 % Distribution network: 34.6 % External R&D laboratories: 29.5 % Other firms: 10.2 %		Number of different external sources used (0 to 16)

Table 4 (*Continued*)

Study	Adoption of inbound activities[a]	Adoption of outbound activities[a]	Scale
Ili et al. (2010)	Customers: 87 % Competitors: 64 % Suppliers: 62 % Lawmaker/Regulations: 59 % Other industries: 48 % Universities: 37 % Research institutes: 36 % Engineers, consultants: 30 % Consortium: 24 % Start-ups: 23 % Communities: 21 %		Four-point scale from 0 = not used, 1 = rarely used to 3 = often used
Lee et al. (2010)	Customers and users: 59 % Competitors in the industry: 56 % Suppliers: 49 % Non-competitors: 43 % Business service providers: 40 % Affiliates: 31 % Universities: 43 % Government agencies: 33 % Non-profit organizations: 31 % Private research centers: 26 %		

[a]Mean scores; standard deviations in parentheses

were using customers and users as information sources. Customers, but also competitors and affiliates, were ranked as the most important information sources. Other external sources, such as private research centers, were used by 26 % of the sample.

The modes of adoption of open innovation found in the various studies are directly compared and summarized in Table 4. Again, a direct comparison between studies is difficult because of the different methods and scales used. However, a few trends are visible.

First, the adoption of inbound activities is higher than the adoption of outbound activities. This is true in all studies where both sides were measured (Drechsler and Natter 2008; Lichtenthaler 2008; Schroll and Mild 2011a; van de Vrande et al. 2009a; Chiaroni et al. 2009). Drechsler and Natter (2008), who measured adoption using the breadth and depth scale introduced by Laursen and Salter (2006), found that inbound activities were used almost 2.5 times more than outbound activities (6.20 versus 1.74) in their sample from 2007. This finding was confirmed by Schroll and Mild (2011a), but to a lower degree (4.03 versus 2.92).

Other studies do not have a combined inbound or outbound scale and allow comparison at the activity level only. Here, again, we see that inbound activities are clearly used more often than outbound activities (van de Vrande et al. 2009a; Chiaroni et al. 2009). At the activity level, cooperation with customers is the most frequently used inbound activity, with 97 % (van de Vrande et al. 2009a), 59 % (De Backer et al. 2008), 65 % (Belussi et al. 2010), and 59 % (Lee et al. 2010) of firms using it, or 5.54 on a 7-point scale (Schroll and Mild 2011a). Cooperation with suppliers, lead users, universities, and R&D institutes also have reasonably high adoption rates, ranging between 30 % and 60 % across all studies. On the other hand, licensing activities, patent acquisitions and the use of communities have lower adoption rates of 10 to 20 %. This is also true for outbound activities, with only 10 % of firms using licensing (van de Vrande et al. 2009a).

Again, it is difficult to compare the studies using the breadth and depth construct of Laursen and Salter (2006), which Drechsler and Natter (2008) and Schroll and Mild (2011a) measured on a seven-point scale, with studies measuring adoption in percentages using a binary scale. In this context, the breadth and depth scale has the advantage of showing adoption as a two-dimensional construct (number of sources used and importance of sources). It is also already used in large European innovation surveys (CIS). However, the number of open innovation activities used to create the adoption scale is different in almost every study. One reason for this is that open innovation activities such as the use of innovation intermediaries, innovation communities, internet and social media are advancing quickly, and studies therefore have to continually adjust their scales according to these technological and societal changes.

6 Factors influencing open innovation adoption

Several case studies on open innovation have shown that its implementation seems to require a set of capabilities. Also, there may be certain environmental conditions that influence innovation practices and the diffusion of open innovation (Chesbrough and Crowther 2006). Innovation research has focused on the influence of organizational capabilities (Chesbrough 2006b, 2007; Chesbrough and Appleyard 2007;

Lichtenthaler and Lichtenthaler 2009; Feller et al. 2009). Additionally, the adoption decision is influenced by subjective decisions made by a firm's executive (cf. Lichtenthaler 2008) and/or its promotion by a champion inside the firm (Chesbrough 2006a). However, Christensen et al. (2005) describe open innovation as a reactive response to the challenge of external factors, rather than a proactive action. This indicates that not all determinants of the adoption decision may be influenced by the firm; some are instead a result of the market or technology environment within an industry.

We will structure the findings into three categories: market- and technology-based characteristics, organizational capabilities and human resource capabilities. This distinction has already been used in other studies, for example Fredberg et al. (2008) and Schroll and Mild (2011b).

6.1 Market- and technology-based characteristics

In the absence of empirical studies, it was initially assumed that the use of open innovation might be restricted to certain industries. However, Chesbrough and Crowther (2006) and Lichtenthaler and Ernst (2009) could not find any evidence that particular industry characteristics were any more likely to inhibit adoption. Lichtenthaler and Ernst (2009) found that industry differences had no significance for the level of adoption in their sample and concluded that openness is not mainly determined by industry characteristics. These industry characteristics are presented in this section and summarized in table 5.The most important characteristic of an industry might be the level of technology used within it. van de Vrande et al. (2009a) explored whether manufacturing firms are more involved in open innovation than service firms. They found that outsourcing R&D and licensing intellectual property from other firms in particular was done more frequently in manufacturing. However, venturing is more popular among service firms. They concluded that service firms did not differ from manufacturing firms regarding other open innovation activities. De Backer et al. (2008) mentioned that high-tech industries typically show a higher level of open innovation.

In order to classify the existing industry descriptions, Barge-Gil (2010) used the OECD classification to cluster companies into low-, middle- and high-tech groups. He observed that high-tech firms are more likely to be semi-open innovators. However, his results were unclear as non-high-tech companies were found to be either open or closed innovators. In another approach, Schroll and Mild (2011b) used a three-item construct for the level of technology and found a strong positive influence of a high technology level on the adoption of all open innovation modes (inbound, outbound, and general open innovation adoption). Although open innovation might be useful for low- and medium-tech industries, the current empirical evidence shows that it is more commonly adopted in high-tech environments.

Industry hostility is a construct that comprises several indicators, such as competitive intensity but also the existence of industry price wars or the extent of monopolies within an industry. Researchers have used various scales for this construct. For instance, Lichtenthaler (2009) used the two-item construct of competitive intensity. Industry hostility seems to be a good predictor of open innovation adoption, as firms in a highly competitive environment need to reduce risks through the acquisition of external know-how and innovations or by adopting new forms of customer integration, for instance through product co-creation in online communities.

Drechsler and Natter (2008) found that companies operating in industries with high market competition are increasingly using external sources of innovation in order to boost their innovation success for a limited additional cost. Lichtenthaler (2009) also found a positive effect of competitive intensity on outbound activities. Schroll and Mild (2011b) found a significant positive relation between industry hostility and adoption. However, high industry hostility was found to have no influence on collaboration with competitors; especially in times with stagnating or decreasing demand, every firm fights for itself (Schroll and Mild 2011b). Thus, three studies have found that industry hostility has a positive impact on the adoption level.

Technological turbulence or 'industry speed' is a construct that includes the effects of shorter product life cycles and the rising costs of R&D, both of which are major factors in the trend towards open innovation (Gassmann and Enkel 2004; Chesbrough 2006b). Rapid technological development creates a climate of technological turbulence in an industry. According to Miller (1988), these indicators of technological turbulence clearly positively influence the importance of innovation, and might also influence the adoption of open innovation.

Lichtenthaler (2009) found a positive effect of technological turbulence on the adoption of outbound open innovation. These results were confirmed by van de Vrande et al. (2009b), who studied environmental turbulence and technological newness in technology-sourcing transactions and found a positive relationship between the level of uncertainty and the use of different external technology sources.

Lichtenthaler (2010) found there to be a positive effect on the inbound acquisition mode, while Schweitzer et al. (2011) found that turbulent environments lead to a demand for the integration of different types of external sources, which can lead to a higher success rate from innovations.

Another industry characteristic is 'market uncertainty'. Quickly changing customer needs and other market-based effects force firms to react flexibly to these changes in the market environment. These trends can be summarized under the construct of market uncertainty. Acha (2008) finds that greater demand uncertainty reduces the depth of innovation activities. Consequently, under the pressure of high market uncertainty, firms use more external sources of innovation, but use each to a lesser extent. This generally positive effect on open innovation adoption was also found by van de Vrande et al. (2009b), especially in relation to inbound acquisition activities.

Lichtenthaler (2009) tested the influence of the four-item construct 'transaction rate', which includes the typical level of technology transactions in a firm's industry. They found the transaction rate to have a significant moderating effect on open innovation strategies.

6.2 Organizational capabilities

One of the issues that is most often discussed in empirical open innovation literature is the relationship between the internal R&D activities of a firm and the level of open innovation used. While some studies propose that open innovation is a substitute for internal R&D (Laursen and Salter 2006; Faems et al. 2010), others find the two to be complementary (van de Vrande et al. 2009a; Lichtenthaler and Ernst 2008, 2009).

Recent studies also indicate that internal and external sources of innovation are used as complements for one another (Barge-Gil 2010). According to Lazzarotti et al. (2010, 2011), open innovators spend significantly more on R&D and, as a part of this effort, they also spend on opening up their innovation process. This was also found by Podmetina and Väätänen (2011). Another explanation for this finding could be that prior investment into internal resources and competences is required before a firm is able to open up.

However, none of the above studies distinguished between the inbound and outbound modes. Schroll and Mild (2011a) found that, generally, open innovation seems to be a complement to internal R&D but that an increased use of inbound activities is used as a substitute for internal R&D. In other words, if a company is relatively closed, R&D intensity will be low. With increased adoption of open innovation, the level of R&D intensity will also rise. However, the more a company is engaged in outbound activities, the lower the level of R&D intensity will be, in comparison to companies that engage solely in inbound activities (Schroll and Mild 2011a). This perspective could bring together the contrary findings of the inbound-focused studies of Laursen and Salter (2006) and Faems et al. (2010) and the mostly outbound-focused studies of Lichtenthaler and Ernst (2008, 2009) and van de Vrande et al. (2009a).

Besides R&D intensity also the firm size was used by various studies as a potential influencing variable on adoption. Several open innovation researchers have addressed the size of a firm and its consequences for open innovation. For instance, researchers have focused on the question of whether and how much SMEs are using open innovation (van der Meer 2007; van de Vrande et al. 2009a; Lee et al. 2010).

Laursen and Salter (2006) found a positive relationship between the human capital of a company and the degree of openness. This is explained by larger firms having a stronger technological position and greater resources. This positive relationship was confirmed by Lichtenthaler and Ernst (2009) and Faems et al. (2010). With an extensive dataset drawn from 26 European countries, De Backer et al. (2008) also found that larger firms innovate more openly than small firms.

In their study of Dutch SMEs, van de Vrande et al. (2009a) found that larger SMEs (100–499 employees) have higher levels of adoption than smaller SMEs. In another SME-based study, Lee et al. (2010) explain the reduced openness of SMEs by a number of factors such as 'lack of infrastructure' and 'lack of financial resources'.

Schroll and Mild (2011b) found no correlation between firm size and openness. Barge-Gil (2010) found that large firms tend to be semi-open, whereas closed innovators tend to be smaller (closed < open < semi-open), which precludes a general conclusion on the relationship between openness and firm size.

The strategic breadth and diversification level of a company might also influence open innovation adoption decisions within a firm. Highly diversified firms tend to license technology because of their larger pool of complementary assets (Lichtenthaler 2010) and therefore might use inbound activities to a higher degree. Also, outbound activities may be used more because of the greater knowledge of market needs that comes from high diversification (Lichtenthaler 2008). Lichtenthaler (2008) also found a minor positive impact of technological diversification and international diversification on the extent of external technology acquisition. Strategic breadth is a

construct that includes diversification in the form of product diversification but also in terms of the number of different markets or distribution channels served. Therefore, it is an indicator of complexity. Schroll and Mild (2011b) found that strategic breadth is positively related to the adoption of open innovation. This relationship is positive for all modes of open innovation, but especially for the inbound acquisition mode.

Choice of innovation partners is influenced by the much greater possibilities for communication with partners that are geographically close. Despite globalization, De Backer et al. (2008) found that companies collaborate more with partners that are geographically close. However, they suggest that it is not the geographic proximity itself, but rather the good connectivity with these external partners that boosts adoption.

On the other hand, the empirical data gathered by Belussi et al. (2010) show how firms in the Italian region of Emilia Romagna establish ties with partners at national, European and international levels. 12 % of all ties were located within the region, indicating that geographic proximity has no influence on the level of open innovation adoption.

The findings of Lichtenthaler and Ernst (2009) show that firms with aggressive technology strategies use external technology acquisition to a lesser extent. On the other hand, they rely more on external technology exploitation. Lazzarotti et al. (2010) finds that open innovators choose an aggressive technology and innovation strategy. They argue that opening up a firm to a variety of external partners is part of an aggressive strategy.

Acha (2008) evaluates the role of 'design' capabilities in open innovation. He finds that firms that actively undertake design activities for innovation purposes are more likely to adopt open innovation. By 'design', he does not mean aesthetic design, but the task of conceiving and negotiating boundaries between organizations. Another finding is that open innovators need more highly developed design capabilities. However, according to Acha (2008), this link between design capacity and open innovation practices is not direct, but is an important line for future research.

The construct of patent protection measures the role and importance of intellectual property rights within a company. Lichtenthaler (2009) used a three-item construct to measure patent protection and found, in contrast to his expectations, no significant moderating effect; strong patent protection does not increase the benefits of outbound open innovation.

Drechsler and Natter (2008) used a regression model to test the effects of other variables on their data and found three additional determinants: The short-term orientation of a firm seems to have a significantly positive, but minor, influence on the breadth of inbound activities and a significantly negative impact on outbound activities. The level of customer orientation seems to have a minor positive impact on inbound activities. Drechsler and Natter (2008) also found that rising development costs are an antecedent for the level of inbound activities. Huang (2011) indicated that internal learning capabilities generate and enhance the innovative capability of a firm, which is positively moderated by open innovation.

In some studies, firm age was used as a control variable. However, Drechsler and Natter (2008) and Schroll and Mild (2011b) found no relationship between firm age and adoption.

6.3 Human resource capabilities

While industry characteristics and organizational capabilities have been researched quite extensively, research on human resources capabilities that could influence the adoption decision is scarce. However, the results of the current studies may lead to a fundamental rethinking of the challenges of open innovation and therefore also of the role played by the decision maker in the firm (cf. Lichtenthaler and Ernst 2009). These capabilities could have a strong influence on the firm innovation process (Lichtenthaler 2011).

Chesbrough (2006a) stated that the implementation of open innovation is often promoted by a champion inside the firm. Chiaroni et al. (2009) also emphasized the important role played by the open innovation champion. Company executives and especially the company's board have a special role to play in the transition towards open innovation.

Wincent et al. (2009), Schroll and Mild (2011b) and Drechsler and Natter (2008) all found a relationship between board composition and the form or level of open innovation used by a firm. Schroll and Mild (2011b) found that, when board members tend to have a marketing focus, open innovation adoption is significantly higher, especially in terms of the inbound acquisition mode. However, a board with a technical focus would rather develop innovations internally than acquire external knowledge. In contrast, Drechsler and Natter (2008) found that companies that were strongly influenced by their marketing department were less open to outside ideas. In their study, a technical background seemed to foster open innovation adoption.

The outcome of an innovation project will always be vague. However, the outcome is even more unclear in open innovation projects, which often require certain investments without any certainty over the outcome. Because it is opening up, the firm is even more exposed to risks. Therefore, the adoption of open innovation requires a certain level of risk acceptance among the company's executives. On the other hand, Gassmann and Enkel (2004) stated that cooperation can improve a company's risk position as the risk involved in developing innovations is outsourced. Lazzarotti et al. (2010) indicated that the objective of sharing risks and costs can especially be identified among the cluster of open innovators.

On a related subject, open innovation also requires decision makers to step back from actively controlling the innovation process. With open innovation, the company loses influence as the number of external collaboration partners increases. Therefore, if managers are not willing to give away control, it is unlikely that a company will adopt an open innovation strategy. Schroll and Mild (2011b) termed this ability 'controllability' and described it as the desire of a person to stay in control of something. They found that the controllability of managers has a large, significant and negative effect on all modes of open innovation adoption, especially on inbound cooperative activities.

We conclude that the adoption of open innovation methods seems to be determined by a number of external factors. While some of these factors depend on the characteristics of the industry or environmental moderators (Lichtenthaler 2009), others relate to organizational structures (cf. Chiaroni et al. 2010) or company executives, which means that firms can influence them. Therefore, the development of managerial competences related to outbound open innovation may also pay off (Lichtenthaler 2009).

Table 5 Relationships found between determinants and open innovation adoption (market-based characteristics)

Determinant	Positive	No effect	Negative
Industry characteristics		Lichtenthaler and Ernst (2009)	
Technology level	De Backer et al. (2008) Schroll and Mild (2011b)	van de Vrande et al. (2009a)	
Industry hostility	Drechsler and Natter (2008) Schroll and Mild (2011b) Lichtenthaler (2009)		
Technological turbulence, industry speed	Lichtenthaler (2009) Schweitzer et al. (2011)		
Market uncertainty	Acha (2008)		
Transaction rate	Lichtenthaler (2009)		

These identified factors provide a valuable basis for future research and enable an ex-post explanation of the open innovation behaviors of firms.

The prevalence of market- or technology-based characteristics, such as a high level of technology or industry hostility, seems to foster open innovation adoption, or at least to be a neutral factor. As Table 5 shows, except for the construct of industry hostility, which three studies found to have a positive effect, all of the other determinants of open innovation adoption need to be researched in more detail. The level of technology was found to be a positive factor by De Backer et al. (2008) and Schroll and Mild (2011b), but a neutral one by van de Vrande et al. (2009a). Similarly, for the construct of technological turbulence (or industry speed), Lichtenthaler (2009) found a positive effect, but Schroll and Mild (2011b) found no significant effect. In the case of market uncertainty and transaction rates, more studies are needed to confirm the findings of Acha (2008) and Lichtenthaler (2009).

Organizational capabilities too need to be researched in more detail and the factors identified so far need to be confirmed by other studies. While the effect of R&D intensity has been the subject of some debate, several recent publications have come to the conclusion that open innovation is complementary to internal R&D activities. Schroll and Mild (2011a) presented an explanation that may integrate the seemingly opposing findings of both a positive and a negative relationship. Also, the influence of firm size on open innovation adoption has already been investigated by several studies and, except for one, all find a positive effect of firm size on the level of open innovation adoption. However, other determinants of open innovation adoption have not been researched to the same extent and confirmation of the existing results is required. This would be especially interesting in the case of 'geographic proximity' and 'technology aggressiveness', where studies to date have revealed diverging results (see Table 6 for details).

The perspective of human resource capabilities in open innovation has already been covered in the theoretical groundwork and qualitative case studies but quantitative empirical work could focus more heavily on these aspects. Drechsler and Natter (2008) and Schroll and Mild (2011b) confirmed the important role a firm's board

Table 6 Relationships found between determinants and open innovation adoption (organizational capabilities)

Determinant	Positive	Neutral (no effect)	Negative
R&D intensity	Schroll and Mild (2011a) van de Vrande et al. (2009a) Lichtenthaler and Ernst (2008, 2009) Chesbrough and Crowther (2006) Barge-Gil (2010) Lazzarotti et al. (2010, 2011) Podmetina and Väätänen (2011)		Laursen and Salter (2006) Faems et al. (2010)
Firm size	Laursen and Salter (2006) Lichtenthaler and Ernst (2009) Lichtenthaler (2008) van de Vrande et al. (2009a) Faems et al. (2010) De Backer et al. (2008)	Schroll and Mild (2011b)	
Strategic breadth and diversification	Schroll and Mild (2011b) Lichtenthaler (2008)		
Geographic proximity	De Backer et al. (2008)	Belussi et al. (2010)	
Technology aggressiveness	Outbound: Lichtenthaler and Ernst (2009) Lazzarotti et al. (2010)		Inbound: Lichtenthaler and Ernst (2009)
Design capabilities	Acha (2008)		
Patent protection		Lichtenthaler (2009)	
Short-term orientation	Drechsler and Natter (2008) (inbound)		Drechsler and Natter (2008) (outbound)
Customer orientation	Drechsler and Natter (2008) (inbound)		
Rising development costs	Drechsler and Natter (2008) (inbound)		
Firm age		Drechsler and Natter (2008) Schroll and Mild (2011b)	

plays in determining the degree of open innovation adoption. Lazzarotti et al. (2010) focused on risk attitude. Future studies could research the influence human-level decisions have on open innovation adoption behavior. However, this level seems to be one at which great differences emerge, even between peers in the same industry.

7 Discussion and future research directions

In this article, we presented and critically reflected the findings and the research methodologies employed by previous empirical research on the adoption of open innovation approaches in business practice. To our knowledge, this state-of-the-art article is the very first to focus solely on quantitative-oriented empirical research. Because of the number and type of quantitative studies available, we set the focus of this article on open innovation adoption. This literature review is subject to several limitations. First of all, this state-of-the-art article explicitly focuses on large-scale empirical open innovation research, especially studies on open innovation adoption that make clear reference to the open innovation concept. We have set our search criteria to reflect this relatively narrow focus in order to make our studies more comparable with each other. Nevertheless, we believe that no studies have been omitted that would have qualitatively changed the paper's main findings. We reviewed all important international journals as well as papers' references, and also included dissertations and working papers.

This section aims to summarize our findings and compare them with previous reviews of open innovation research. In this section, we also summarize the answers to our research questions.

7.1 Current state and conclusions of empirical open innovation research

It can be stated that the concept of open innovation is already being adopted by a significant percentage of firms, depending on the study referred to, up to 45 %. The studies reviewed in this paper show that open innovation, as a one-dimensional construct, is adopted in 20 to 45 % of the samples. However, this relatively high level of open innovation adoption is largely a result of the adoption of inbound open innovation activities. The inbound mode is clearly more frequently used than the outbound mode. In particular, cooperation with customers and suppliers were identified as the open innovation activities adopted most often, while outbound activities such as licensing and venturing are only adopted by minorities of between 10 and 30 %. Differences in adoption by firms can be explained by the structural characteristics of the market or technological drivers. Additionally, a number of organizational characteristics and human resource capabilities have been identified as determinants.

Based on the current empirical evidence on open innovation adoption, it can be seen as a global trend occurring in almost all industries and markets. It will be worth monitoring this trend as it evolves over the years using longitudinal data to see whether changes in the technology base of industries are reflected by changes in the search patterns of firms (Laursen and Salter 2006; Chiaroni et al. 2009; Lichtenthaler 2009).

Open innovation research often focuses on restricted units of analysis, such as adoption in SMEs, in certain countries or regions, or in single industries. Comparable studies at a global level, however, could be useful for comparing the evolution of open innovation across industries and countries. Future research should also include all modes of open innovation, as the current work usually focuses on either inbound or outbound modes.

The empirical research to date has often focused on either the USA or Europe, and has left out some other regions, such as Asia (van de Vrande et al. 2010) and South America. Although Lee et al. (2010), Chiang and Hung (2010), and Xiaoyuan and Yanning (2011) have recently presented empirical studies on open innovation in Taiwan and South Korea, these areas are currently underrepresented in open innovation research.

7.2 Suggestions for research methodology

Prior studies have used easily available secondary data, such as the CIS. Although these databases provide large-scale evidence regarding open innovation adoption, they are usually less focused on the existing theories of the phenomenon and its drivers. There are indicators of open innovation that are still missing from these databases. Therefore, existing government or NGO surveys need to be adapted, or the scientific community will need to create its own large-scale empirical databases.

For measuring the extent of open innovation adoption, the existing studies often use subjective scales. Although these scales have the advantage of better reflecting the individual strategic importance of open innovation activities within the firm (Lichtenthaler and Ernst 2009) and offer improved comparability over different company types and industries, attempts to a more generic measure of open innovation adoption should be made to validate the existing findings and make studies more comparable with each other.

This would make the measurement of open innovation much more comparable over different industries, countries and, especially, time. We have shown that the results of our selected studies are often not directly comparable because of extensive differences in the methods or measures used. The development of a unique measurement scale for open innovation activities will also require a unique definition of open innovation in the minds of all researchers. An exact definition will be tough to produce, as openness now takes different forms than it did in the past (Dahlander and Gann 2010) and the definition of openness might thus need updating. As a result of different scales and different definitions of openness, cluster sizes and adoption rates vary widely in the existing studies (Laursen and Salter 2006; van der Meer 2007; van de Vrande et al. 2009a; Batterink 2009). Scales for open innovation are often based on the binary indicators of the CIS. Barge-Gil (2010) mentioned that a continuous indicator would be preferable.

7.3 Future research directions

We have seen that open innovation depends on several industry characteristics. These drivers of open innovation need to be researched in more detail, ideally using large-scale cross-industry and cross-country studies. For instance, Chiaroni et al. (2009) suggest that further detailed research is required on the influence of environmental characteristics. Other influencing variables at the organizational and human level also need to be researched in more detail (cf. Elmquist et al. 2009). Future research could build on this differentiation between industry-level, firm-level and individual-level variables, as suggested by Lichtenthaler (2011). Additionally, the analysis of determinants at a project level (cf. Lichtenthaler 2011;

Barge-Gil 2010) could help to link open innovation adoption behaviors with specific organizational processes and decision makers.

Existing research has often focused on either the inbound or the outbound mode of open innovation. Only a few have used an integrated point of view, often as a result of the unavailability of data for both modes. Future studies could integrate the two modes and investigate the supposed shift from inbound to outbound adoption of open innovation activities (Schroll and Mild 2011b).

Furthermore, firms do not use a generic strategy for every innovation project. Barge-Gil (2010) calls for a measurement of openness, not only for the entire firm or the entire innovation strategy, but also at the individual project level. Future research could further investigate adoption at this detailed level.

The impact of open innovation on firms' innovation performance has been explored by some studies (e.g. Drechsler and Natter 2008; Chiang and Hung 2010). The research has usually focused on the value-enhancing effects of open innovation, but not on the increased costs of a more diverse technology alliance portfolio (Faems et al. 2010). Further research on the impact of open innovation on a firm's financial performance could help to demonstrate the legitimacy of open innovation as an important research field (Lichtenthaler 2011).

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