

R&D AND OPEN AND CLOSED INNOVATION

1. Introduction. Research and Development (R&D) activities are generally viewed as important contributors to innovation. R&D can have a direct role through generating new knowledge or its role can be indirect by increasing the ability of firms to absorb knowledge from external sources (Cohen and Levinthal, 1989, 1990, 1994). Because of its dual functions, R&D can be central to both open innovation in which new technologies are developed with the assistance of external sources such as suppliers, customers, users and competitors (Chesbrough, 2003) and in closed innovation, when firms rely heavily (perhaps exclusively) on their own resources to develop and implement new technologies. Firms can also innovate without performing R&D, with survey data from Europe showing that approximately half of innovative firms do not perform R&D (Huang et al, 2010; Arundel et al, 2008).

In this paper, we examine the relationship between the R&D status of firms and their use of open and closed methods of developing product, process and organisational innovations. Drawing on data from over 3,800 European firms, we conclude that open innovation, far from being a rare activity, is very common in situations in which firms do not have and do not wish to invest in the non-core capabilities necessary to develop and implement innovations that nevertheless are valuable enhancements to their current product, process and organisational repertoires. R&D status, however, has only a marginal effect on the choice between open and closed methods of innovation.

In Section 2, we present a typology of open innovation. This is followed in Section 3 by a discussion of innovation, R&D and absorptive capacity. The characteristics of our data are described in Section 4 and the results of our analyses are presented in Sections 5 and 6. We conclude with a discussion of the implications of our findings and suggestions for further research.

2. R&D and Open Innovation. According to Google Scholar, as of 30 June, 2013 the term ‘open innovation’ was present in the titles of around 3,750 articles and had appeared somewhere in the texts of 587,000 works. Unfortunately, one reason for its popularity is that the expression is imprecise (Helfat, 2006) - that it has become an ‘umbrella term’ (Acha, 2007) that has different meanings in different contexts.¹ Chesbrough (2006a, 1), the most important apostle of open innovation, has provided a definition which summarises both the scope and the flexibility of the concept:

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. Open Innovation is a paradigm that 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. Open Innovation processes combine internal and external ideas into architectures and systems (Chesbrough, 2006a, 1).

In this characterisation, open innovation is a collection of different types of activities. Its scope is very broad and it is not a binary phenomenon, but one that occurs along a spectrum of degrees of openness (Dahlander and Gann, 2010). Open innovation can apply to implementation as well as development since new ideas or artefacts may need to be assimilated into an organisation's current operations and structure, requiring external intervention to effect adjustments or modifications to both new and existing parts of a broader system in order to optimise efficiency. Although originally intended to apply to high technology firms, open innovation has since been extended to cover low-tech firms as well (Chesbrough and Crowther, 2006; Chiaroni, et al., 2010; Spithoven, et al., 2010).

To operationalize the concept, we examine what constitutes open or closed innovation by surveying the mechanisms that can be used to achieve inbound open innovation and measuring the distribution of firms using each mechanism.² We focus directly on the activities of different participants in innovation across an array of open and closed innovation methods. Our classification embraces four stages which describe a progression from open innovation in the first three stages to closed innovation in the last. In general, the contribution of each firm to the development of an innovation is expected to increase from the first to the fourth stage. The first two stages are characterised by the acquisition of embodied knowledge from external sources, the third stage by collaboration, and the fourth stage by in-house development, or closed innovation.

1. *Technology adoption*: Firms can acquire innovative products and processes and organisational practices from sources external to the firm, with little or no further work required. For example, a computer assembler can purchase faster hard drives or wireless cards from specialist firms to include in a notebook computer.
2. *Customising or modifying products, processes or organisational methods obtained from external sources*, including the innovative use of existing engineering knowledge (Kline and Rosenberg, 1986).

3. *Generating new knowledge through collaboration* is an advanced form of open innovation that draws on more extensive and intensive capabilities than are needed for the first two stages. Firms that do not want to acquire in-house skills to develop an innovation entirely on their own may instead opt to combine internal competences with those of suppliers, customers, competitors, universities and consultants to generate innovative knowledge.
4. *Developing new or improved process or product technologies or organisational forms entirely in-house*, in other words, closed innovation.

On the basis of our database, which is described in detail in Section 4, we can reveal the extent to which a sample of 3,828 European firms engages in each of these categories. As **Table 1** shows, both open and closed innovation were undertaken by nearly two-thirds of all innovative firms. Of the others, 15.3 percent used open innovation exclusively and 18.3 per cent were only closed innovators. Among the 81.7 per cent of firms that engaged in open innovation either exclusively or in conjunction with closed innovation, all of the three methods of open innovation were widely used and they were of nearly equal popularity. The appropriate interpretation of these findings depends on the definition of open innovation that we adopt. If we accept Chesbrough's (2006a) definition (as we do), then open innovation is widespread, but if we interpret open innovation more narrowly as a strategy or business model (Gianiodis et al., 2010), then it is quite rare. This latter finding is consistent with that of Lichtenthaler (2008), who determined that only a small proportion of firms are open innovators even though many more engage in occasional inward and outward open innovation.

Because our typology concentrates not on strategies, but on activities, our work does not correspond directly to the schemata of Lichtenthaler (2008), Chesbrough (2003, 2006b) and Gianiodis et al. (2010). By concentrating on the activities of firms that seek knowledge from external sources, however, we are able to discriminate more finely between aspects of the ways in which inbound open innovation is undertaken in practice. We do not regard open innovation as a goal in itself, but as a way of achieving innovative outcomes that in different contexts might well be accomplished using other methods, notably closed innovation.

3. R&D Status and open and closed innovation. Although R&D has long been known as an important contributor to innovation (Popp et al., 2010), it is far from being the only important factor

in technological change (Smith, 2005) and its significance is likely to vary depending on the nature and context of the innovation in question. R&D is probably rare for technology adoption, for example, and it may or may not be involved in the other three categories, including closed innovation.

There are many ways that firms can innovate, including through closed innovation, without investing in R&D. For instance, innovation processes in low- and medium-technology industries are often less dependent on R&D than in high-technology sectors and more related to modification and incremental change, design and process optimisation (Hansen and Serin, 1997; Santamaria et al, 2009) as well as exploiting knowledge sources such as suppliers (Hervas-Oliver et al, 2011). Service sector firms innovate in a continuous, incremental way, with many people from different divisions involved. This manner of innovating makes it difficult to identify specific non-technological innovations (Tether, 2005; Gellatly and Peters, 1999).

Incremental change can depend on learning by doing, as a firm gets better at what it already does (Cohen and Levinthal, 1989). This category includes imitation such as reverse engineering, when firms attempt to replicate products or processes (or parts of products and processes) that are already available. Another method of innovating without R&D consists of combining existing knowledge in new ways. These activities can include some types of industrial design and engineering projects (Grimpe and Sofka, 2007; Huston and Sakkab, 2006). The Italian ‘informal learning systems’, characterised by small and medium-sized firms in traditional industries and in mechanical and electrical/electronics sectors, use these methods to create new products (Evangelista et al. 2002). These systems build on tacit knowledge, engineering skills and cumulative learning processes, where the necessary knowledge is located in the system, rather than in a specific firm (Gottardi, 1996). Informal contacts and mobility of highly-skilled personnel move tacit knowledge from firm to firm.

Nevertheless, firms that perform R&D have a broader set of capabilities and options for developing innovations in-house than firms that do not perform R&D. This leads to our first hypothesis: **H1. Innovative firms that engage in R&D are more likely to undertake closed innovation than innovative firms that do not engage in R&D.**

Alternatively, although R&D has been regarded traditionally as an in-house activity that firms undertake primarily for their own benefit, the role of R&D in open innovation has also been debated

extensively in recent years (Grimpe and Sofka, 2009; Enkel et al., 2009; Schroll and Mild, 2011). The use of R&D to ease the acquisition of external knowledge (Dahlander and Gann, 2010) is an obvious search strategy because of its connection with absorptive capacity (Grimpe and Sofka, 2009). Firms that engage in R&D in a given field are potentially in a better position both to acquire external knowledge and to assess its value than are firms that abstain from R&D because state-of-the art research requires an up-to-date knowledge of what other researchers are doing and of the gaps that remain, which improves appreciation of the usefulness of novel approaches that have been developed externally (Cohen and Levinthal, 1989 and 1990). A record of engagement in R&D also makes a firm more attractive as a collaborator as it is more likely to be able to contribute expertise to successful development activities. **H2.** *Because innovative firms that engage in R&D have higher levels of absorptive capacity, they should be more active in open innovation than innovative firms that do not engage in R&D, especially in the category of collaborative development.*

It is also probable that the relationship between R&D capabilities and innovation is not straight-forward and that profit-seeking firms take additional factors, such as cost considerations, into account when deciding whether to develop innovations in-house, draw on external sources of innovation, or use a combination of these two methods. One view depicts firms as rather conservative in terms of new R&D spending, even with fundamental product and process innovation. For example, Kline and Rosenberg (1986) argue that when firms are faced with having to innovate they first look into their existing stock of knowledge. If the necessary capabilities are missing, they prefer to first consult external sources with which they are already familiar, especially if they have ‘strong ties’ to productive networks (Gianiodis et al., 2010). This suggests that firms that do and do not perform R&D will be equally likely to use technology adoption: **H3.** *Both innovative firms that do and do not perform R&D will rely on external knowledge if it is more efficient to buy an innovation than to make it in-house. This should be most visible for technology adoption, where there should be little difference in its use by R&D performing and non-R&D performing innovative firms.*

In addition, the relationship between R&D and absorptive capacity and their effects on open innovation are not always clear-cut. It costs money to build and maintain absorptive capacity through any channel. As a result, small firms or those that believe they are cash-strapped will adopt strategies

that fit their available resources, which may mean no formal R&D and very informal and truncated external search activities. For these firms that do not have well established development capabilities, successful innovation may be based instead on knowledge and expertise that they obtain from suppliers, customers or other external sources such as contractors. **H4.** *Although both innovative firms that do and do not perform in-house R&D will look for innovative knowledge through user-producer (von Hippel, 1988, 2005) and supplier-producer (Pavitt, 1984) relationships, these will be more common for firms that do not perform R&D in-house.*

4. Methodology. Our data are obtained from the European Commission's Innobarometer 2007 survey which drew a random quota sample of firms with 20 or more employees from Dunn and Bradstreet data for each member state of the European Union, with a specified number of responses for each country. The smaller countries and new member states were over-sampled in comparison to their economic weight within the European Union. To counteract this, all statistical results such as frequencies are reweighted to balance the sample to the actual number of firms in each country (the tables also give the unweighted number of respondents used to calculate the frequencies). Further information on the sampling method and the complete questionnaire (in English) are available in the Innobarometer report (Gallup, 2007).

As non-innovative firms did not answer the questions on innovative activities, only the results for innovative firms are given here. To be classified as innovative, a firm had to report at least one product, process or organizational innovation in the two years before the telephone interview. All results are limited to a maximum of 3,828 self-reported innovative firms that also answered the questions on open and closed innovation.³

The 2007 Innobarometer survey includes questions that had not been included in the European Community Innovation Surveys (CIS). Innobarometer questions that were later adopted by the CIS are linked to the question on 'who developed' product, process and organizational innovations. In particular, the Innobarometer questionnaire introduced a new question which asks if the firm innovated through customising or modifying products or processes that were originally developed by others.

The firm's sector of activity is based on the NACE classifications available from Dunn and Bradstreet for each firm. These were reassigned to five sector groups, as shown in **Table 2**. Dunn and Bradstreet data were also used to assign respondent firms to one of three size classes: 20 to 49 employees, 49 to 249 employees, and 250 or more employees.

5. Results for R&D activity. **Table 3** gives the distribution of R&D status by firm size and sector. The 271 firms (7.1% of the total) that are listed as 'contract R&D' do not perform R&D in-house but reported 'contracting out R&D to other companies, consultants, universities or research institutes'. The 1,650 firms (43.1%) of the total listed under 'no R&D' neither performed R&D in-house nor contracted out R&D. Due to the small number of contract R&D firms, some of the results given below exclude this group.

After weighting, 52.5% of the 3,828 firms are non-R&D innovators, 40.0% are in-house R&D performers, and 7.5% are contract R&D performers. The share of non-R&D innovators is similar to the 46% share observed by Huang et al (2010) using CIS-3 data for a selected group of countries.

As shown in **Table 3**, a higher percentage of non-R&D innovators compared to R&D performers have fewer than 50 employees (63.5% versus 50.9%) and are active in low technology service sectors (32.8% versus 21.3%). However, non-R&D innovators are found in all size categories and sector classes. For example, 9.2% of non-R&D innovators have over 250 employees, while there is only a relatively small difference in the percentage of non-R&D innovators and in-house R&D performers active in knowledge service sectors: 16.9% versus 22.2%.

Furthermore, the Innobarometer survey asked all firms if they introduced a product, process, or organisational innovation "without using R&D (either in-house or contracted out R&D)" in the preceding two years. By definition, firms in the sample without in-house capabilities answered affirmatively, but it is noteworthy that 68.3% of R&D performing firms also introduced at least one innovation without the need for R&D, as did 63.8% of firms that relied on contract R&D. This not only provides further empirical confirmation of the concept of 'hidden innovation', which argues that innovating without R&D is common (Harris and Halkett, 2007; Barge-Gil et al., 2011), but it reinforces the observation that firms exercise a high degree of flexibility in the use of methods employed in innovation irrespective of whether they have developed their own R&D capabilities.

6. Results for open and closed innovation. *6.1 Results by firm sector and size.* Many of the following tables give the percentages of firms that report using each of the four open and closed innovation methods for at least one of the three innovation types: products, processes, and organisational methods. In addition, results are given for three categories: firms that only report the use of open innovation methods (one or more of technology adoption, modification, or collaboration), firms that only report closed innovation (they only develop innovations in-house), and firms that report *both* open and closed innovation.

Table 4 reports, for each sector, the proportions of firms that use each type of open and closed innovation. All four innovation methods are relatively common, with at least 40 per cent of firms in all sectors using each method. The distributions for low tech manufacturing, medium and high tech manufacturing, and knowledge services are similar, although a higher proportion of medium and high tech manufacturing and knowledge services firms engage in collaboration. This may be because medium and high tech manufacturing and knowledge services firms are more likely to have something new or distinctive to offer to potential partners than is true of low-tech manufacturing and services firms and of those in utilities and construction, another low-tech area.

Importantly, the proportions of firms in low tech services and utilities and construction that only employ open methods is more than double that in the other three sectors, while the proportion that only develop innovations in-house is correspondingly smaller. Taken together, these figures imply that low technology firms employ somewhat different innovation methods, with a greater reliance on external sources, than other firms. Straight adoption without significant modification and adaptation is notably common for low-tech service firms, which may indicate that their needs are more highly standardised or that their in-house innovation capabilities are lower than for firms in other sectors.

Table 5 shows the relationship between firm size and open and closed innovation. Large firms (those with 250 or more employees) are more active in all types of open and closed innovation, perhaps because their activities are more numerous and diverse and because they have the resources to cultivate a broader range of technical capabilities. Small firms (20-49 employees) are more likely to use technology adoption than medium-size firms are and correspondingly less likely to engage in

modification. Although we do not have direct data, this may be because very small firms have fewer or more highly focused technical capabilities than medium-size or large firms.

6.2 Results by R&D status. **Table 6** gives the percentage of firms, by R&D status, that use each of the open and closed innovation methods and the percentages that only use open methods, only use closed methods, and which use both open and innovation methods. The results show clearly that closed innovation, which we define as innovation based on knowledge developed in-house, is performed by three-quarters or more of firms in each of the three R&D status categories. The highest rate of closed innovation, 94.0%, is for firms that perform R&D in-house.

On the other hand, over 80% of firms for each R&D status category also engage in one or more types of open innovation. The data suggest that the relationship between open and closed innovation methods and R&D status is not strong, although the differences by R&D status are statistically significant due to the large sample sizes. The only exception is for the percentage of firms that are open innovators only, where only 6% of in-house R&D performers are in this category compared to 21.5% of non-R&D performers and 25.1% of contract R&D performers.

The high proportions of firms of all types of R&D status that engage in both open and closed innovation may also imply that the decision to innovate using external knowledge sources is ad hoc and contextual – that access to in-house or contract R&D inputs does not deter firms from undertaking open innovation if there are advantages to acquiring knowledge through these methods. However, the greater tendency of firms with in-house R&D operations to engage in open innovation via modifying technology and particularly through collaboration, in comparison to firms that do not perform R&D, also suggests that there is a positive relationship between undertaking R&D, absorptive capacity, and open innovation, as argued by Grimpe and Sofka (2009) and Dahlander and Gann (2010).

Of the four innovation methods in **Table 6**, the largest differences in behaviour between firms with no R&D activities and those with in-house R&D capabilities are in developing entirely new or significantly new products, processes or organisational methods in house or in collaboration with others. In both cases, firms with in-house R&D capabilities are substantially more active. In fact, the tendency of firms with no R&D activities to engage in collaborative development is the lowest of any findings for firms of all types, including contract R&D performers. This could mean that some

potential partners demand more than non-technical complementary capabilities when entering into collaborations. Conversely, the proportion of firms that use technology adoption is similar for firms that do and do not perform R&D. This indicates that an ability to develop innovations internally does not discourage firms from engaging in open innovation.

The first three methods in **Table 6**, those associated with open innovation, depend on the diffusion of knowledge in either embodied or disembodied form. Non-R&D performers are slightly more dependent on methods based on the diffusion of knowledge. Although 80.5% of non-R&D innovators develop at least some innovations entirely or partly on the basis of diffused knowledge (in other words, employ open innovation), only 78.5% use only internally acquired knowledge for at least some innovations. For firms that undertake in-house R&D, however, 82.0% innovate through open innovation, but even more (94.0%) develop innovations internally. Non-R&D performers are also relatively more dependent on embodied knowledge (the first two methods), with much lower use rates for collaborative innovation. This is in contrast to in-house R&D performers, who are slightly more dependent on collaborative activities than on embodied technology.

Table 7 provides results for all possible combinations of the four innovation methods. Although the proportions of both in-house and non-R&D performers that only engage in collaborations or in adoption and collaboration or modification and collaboration are very small, in-house R&D performers engage substantially more frequently than non-R&D firms in the three categories of collaboration and in-house development; adoption, collaboration and in-house development; and modification, collaboration and in-house development.

The results in **Tables 6 and 7** strongly support our first two hypotheses. Firms that undertake in-house R&D activities are more likely than non R&D performers to engage in both open and closed innovation. This is especially true in the case of collaborative development. However, an alternative hypothesis to H2 is also partly supported – firms that do not perform R&D are more likely to engage *exclusively* in technology adoption or in customising or modifying products, processes and organisational methods obtained from external sources than firms that perform in-house R&D. Conversely, the proportion of in-house R&D performers that engage in all four innovation methods (25.9%) is much greater than the proportion of non-R&D performers (15.9%).

Our third hypothesis is seemingly confirmed by the data in the first line of **Table 6**. In aggregate, nearly half of the firms in both R&D categories engage in technology adoption and the proportions are relatively similar. **Table 7** shows, however, that the proportions of non-R&D firms that are only adopters or that only adopt and modify are substantially greater than the proportions of in-house R&D performers, but this is largely compensated for by the much higher proportion of in-house R&D performers than engaged in all methods. On balance, therefore, it seems that adoption *per se* is more closely associated with firms that do not perform R&D themselves.

The fourth hypothesis is partly confirmed. **Table 8** gives the share of firms by R&D status that used each of four external information sources to customise or modify products and processes. The data are limited to firms that report modification. Firms that do not engage in R&D are slightly less likely to use customers as information sources for customising or modifying products and processes than firms that perform R&D internally. This is also true for the use of information from developers or suppliers for *product* innovations. However, for *process* innovations (the category that Pavitt (1984) originally targeted), firms that do not engage in R&D are somewhat more likely to consult developers or suppliers when making changes. The principal message of **Table 8**, however, is that firms of both R&D categories engaged in modification rely on information from suppliers and developers and, when appropriate, from customers.

7. Discussion and conclusions. Our results show that both open and closed innovation were undertaken by approximately two-thirds of all innovative firms. Of the others, 15.3 percent used open innovation only and 18.3 per cent were only closed innovators. Among the 81.7 per cent of firms that engaged in open innovation either exclusively or in conjunction with closed innovation, all of the three methods of open innovation were widely used and of nearly equal popularity. The interpretation of these findings depends on the definition of open innovation that we adopt. When a narrow definition (Gianiodis et al., 2010) is used, open innovation is quite rare, but it is common if we accept Chesbrough's (2006a) more inclusive definition.

Our data indicate that undertaking in-house R&D makes it somewhat easier to engage in both open and closed innovation. However, firms that do not undertake formal R&D innovate very frequently on the basis of in-house development and firms with R&D capabilities often develop

innovations without performing R&D. Therefore, performing R&D in-house can be either a complement or a supplement to open innovation, or indeed to innovation in general, depending on context. Finally, using the services of original developers or suppliers is the most common way of obtaining information for modification or customisation of products or processes obtained from external sources. Depending on circumstances, substantial proportions of firms also gather information from other companies that use similar products or processes, from customers and from external sources of expertise such as consultants or universities.

So far, our discussion has concentrated primarily on differences in the distribution of methods for innovation. Because of the large size of the sample, almost all of our findings are statistically significant. Nevertheless, there are few if any cases in which it is legitimate to assign a particular type or method of innovation to one class of firms or another. All kinds of innovation are undertaken in substantial proportion by firms of all types, and they all draw on largely the same external sources. Furthermore, the use of R&D for developing innovations is optional even for firms that possess in-house capabilities. This is not particularly surprising in that a given set of R&D capabilities is unlikely to cover all potential needs, even for relatively large firms. Our data are consistent with the concept of firms choosing the combination of inputs they need depending on the nature of the innovation under consideration. 'Ad hoc' does not mean 'random', but only that the activities used are based on the particular circumstances under which a firm is operating in a given situation. Therefore, firms with a variety of needs can be expected to draw on a variety of ways of meeting them.

This suggests that further investigations should not concentrate on the extent to which firms engage in open or closed innovation, no matter how defined, or on whether firms in general should make open innovation a central plank of their strategic platforms. Our data indicates that most firms already draw heavily on external sources for their own innovations. Research can instead revert to the broader and more traditional questions of which activities are most conducive to successful innovation and of how external and internal inputs, including R&D, can be blended when innovating. Attention should also be devoted specifically to studying the methods used by the high proportion of firms that innovate without using any R&D.

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Table 1. Methods used in innovating in the previous two years (per cent of all firms)

Method	Total
<i>Number of firms</i>	<i>3,828</i>
1. Selling on products or acquiring processes or organisational methods from external sources with little or no modification in-house (Adoption)	53.1%
2. Customising or modifying products, processes or organisational methods obtained from external sources (Modifying)	53.3%
3. Developing entirely new or significantly improved products, processes or organisational methods in collaboration with other firms, consultants, universities, etc. (Collaborating)	47.1%
4. Developing entirely new or significantly improved products, processes, or organizational methods in-house (In-house, i.e. closed innovation)	84.7%
<i>Open innovators only (Used 1-3 exclusively)</i>	<i>15.3%</i>
<i>Closed innovators only (Used 4 exclusively)</i>	<i>18.3%</i>
<i>Open and Closed innovators (Used any of 1-3 and 4)</i>	<i>66.4%</i>

Notes: Results are weighted to reflect the distribution of firms in Europe

Engagement in each development method is based on at least one reported use by a firm of a product, process and organizational innovation. For example, to qualify a firm could have introduced a process innovation but no product or organizational innovations.

Includes contract R&D performers only (6.7% of weighted respondents).

Excludes 441 product, process or organizational innovators that did not answer the questions on who developed their innovations.

Table 2. Distribution of innovative firms by sector (unweighted count data)

Sector Group	Number of Firms	Percent	NACE classes
Low tech manufacturing & resources	1,023	26.7%	Agriculture, fishing, oil extraction, mining, food, textiles, wearing apparel, leather, wood products, pulp and paper, printing, petroleum products, non metallic mineral products, basic metals, fabricated metal products, furniture.
Medium & high tech manufacturing	628	16.4%	Chemicals, rubber and plastics, machinery, office machinery, electrical machinery, telecom equipment, instruments, automobiles, other transport equipment.
Utilities & construction	367	9.6%	Utilities, water, construction, sewage
Low tech services	1,001	26.1%	Wholesale, retail, hotels and restaurants, land, sea and air transport, rentals, personal services.
Knowledge services	809	21.1%	Telecommunications, finance, insurance, real estate, computer and software, R&D, other business activities, education, health, recreation and entertainment.
<i>Total</i>	<i>3,828</i>	<i>100%</i>	

Notes: After weighting: 25.3% of firms are in low tech manufacturing and resources, 14.8% in medium and high tech manufacturing, 11.6% in utilities and construction, 29.0% in low tech services, and 19.3% in knowledge services.

Table 3. Size and sector of innovative firms by R&D status

Characteristic	R&D status			All innovative firms
	No R&D	in-house R&D	Contract R&D	
<i>Number of firms</i>	<i>1,650</i>	<i>1,970</i>	<i>271</i>	<i>3,828</i>
Size				
20-49 employees	63.5%	49.1%	63.8%	57.5%
49-249 employees	27.3%	36.3%	21.1%	30.6%
250+ employees	9.2%	14.6%	15.1%	11.9%
<i>Total</i>	<i>100.0%</i>	<i>100.0%</i>	<i>100.0%</i>	<i>100.0%</i>
Sector				
Low tech manufacturing	22.5%	30.6%	14.7%	25.3%
Medium & high tech manuf	10.8%	20.6%	9.7%	14.8%
Utilities and construction	17/0%	5.3%	10.0%	11.6%
Low tech services	32.8%	21.3%	46.6%	29.0%
Knowledge services	16.9%	22.2%	19.0%	19.3%
<i>Total</i>	<i>100.0%</i>	<i>100.0%</i>	<i>100.0%</i>	<i>100.0%</i>

Table 4. Use of open and closed innovation methods by sector

Innovation method	Low tech manufacturing	Medium & high tech manufacturing	Utilities & construction	Low tech services	Knowledge services
<i>Number of firms</i>	<i>1,023</i>	<i>628</i>	<i>367</i>	<i>1,001</i>	<i>809</i>
Adoption	49.5%	45.8%	53.6%	63.0%	48.2%
Modifying	53.0%	52.2%	47.3%	59.0%	49.4%
Collaborating	47.6%	53.9%	43.8%	40.1%	53.7%
In-house	90.4%	91.5%	76.0%	75.7%	90.9%
Open methods only ³	9.6%	8.5%	24.0%	24.3%	9.1%
In-house only	20.8%	21.1%	14.7%	13.1%	23.0%
Both open and in-house	69.6%	70.4%	61.3%	62.5%	67.9%

See Table 1 for a full definition of each of the four innovation methods.

For each innovation method, the differences by sector are statistically significant with $p < .001$.

Table 5. Use of open and closed innovation methods by firm size.

Innovation method	20-49 employees	50 – 249 employees	250+ employees
<i>Number of firms</i>	<i>1,467</i>	<i>1,330</i>	<i>1,031</i>
Adopting ¹	53.6%	49.3%	60.2%
Modifying ¹	49.6%	57.9%	59.0%
Collaborating ¹	43.9%	46.3%	64.7%
In-house ²	84.1%	84.7%	88.0%
Open methods only ³	15.9%	15.3%	12.0%
In-house only	20.1%	17.4%	12.4%
Both open and in-house	64.0%	67.3%	75.6%

See Table 1 for a full definition of each of the four innovation methods.

1: Differences are statistically significant at $p < .000$.

2. Not statistically significant ($p = .109$).

3. Differences in the distribution of size by the three innovation methods are statistically significant at $p < .002$.

Table 6. Innovation methods by R&D status

Innovation Method	No R&D	In-house R&D	Contract R&D	All firms	p¹
<i>Number of firms</i>	<i>1,650</i>	<i>1,907</i>	<i>271</i>	<i>3,828</i>	
Adopting ¹	54.3%	49.8%	63.1%	53.1%	.009
Modifying ¹	50.5%	56.1%	56.3%	53.3%	.001
Collaborating ¹	36.0%	57.6%	63.1%	47.1%	<.001
In-house ²	78.5%	94.0%	74.9%	84.7%	<.001
Any open innovation method	80.5%	82.0%	87.1%	81.7%	.030
Open innovation methods only	21.5%	6.0%	25.1%	15.3%	
Closed (in-house) innovation methods only	19.4%	18.0%	13.0%	18.3%	<.001 ²
Both open and closed innovation methods	59.0%	76.0%	62.0%	66.4%	

1: The p value is the statistical difference between firms with no R&D and in-house R&D (two-tailed test).

2: Significance of distribution of three innovation categories by R&D status.

Table 7. All possible combinations of innovation methods by R&D status

	Contract RD			
	no R&D	RD in-house	only	Total
Adopting only	7.7%	1.3%	4.0%	4.8%
Modifying only	4.7%	1.7%	2.5%	3.3%
Collaborating only	0.9%	0.6%	6.5%	1.2%
In-house only	19.4%	18.0%	13.0%	18.4%
Adopting and modifying	4.8%	0.6%	1.8%	2.8%
Adopting and collaborating	1.0%	0.1%	1.8%	0.7%
Adopting and in-house	9.8%	4.5%	6.5%	7.3%
Modifying and collaborating	1.1%	0.1%	0.0%	0.6%
Modifying and in-house	6.6%	8.0%	1.1%	6.8%
Collaborating and in-house	8.0%	11.7%	7.2%	9.5%
Adopting, modifying and collaborating	1.4%	1.5%	8.3%	1.9%
Adopting, collaborating and in-house	2.7%	7.7%	4.7%	4.9%
Adopting , modifying and in-house	11.0%	8.3%	7.9%	9.6%
Modifying, collaboration and in-house	5.0%	10.0%	6.9%	7.2%
ALL four methods	15.9%	25.9%	27.8%	21.0%
Total	100.0%	100.0%	100.0%	100.0%

See Table 1 for a full definition of each of the four innovation methods.

Table 8. Information sources used to help customize or modify products and processes obtained from external sources: percent of firms by R&D status reporting each source

Method	Product innovations		Process innovations	
	No R&D	In-house R&D	No R&D	In-house R&D
Original developer or supplier	56.0%	59.0%	64.2%	58.0%
Other companies that use similar products	34.1%	34.0%	34.0%	39.0%
Your customer for these products	52.6%	57.0%	35.6%	39.0%
Experts such as consultants, universities, etc.	23.0%	45.1%	20.5%	39.3%

Statistical significance of differences between non-R&D innovators and in-house R&D performers: For both product and process innovations, only significant for use of experts ($p < 0.001$).

¹ A wide range of authors have presented at least ten classification schemes of relevance to the concept of open innovation, some of which pre-date Chesbrough's pioneering 2003 book. The resulting typologies classify open innovation according to (1) the activities or practices involved; (2) the capabilities required; (3) the degrees to which technology is acquired externally; (4) the methods used to acquire innovative knowledge; (5) the search strategies employed; (6) the characteristics of the firms engaging in open innovation; (7) methods of technology transfer employed; (8) the participants involved in open innovation relationships; (9) the motives for engaging in open innovation; and (10) the stage in an innovation process at which open innovation is used. A selection of relevant works includes Chesbrough (2003), Dahlander and Gann (2010), van de Varande et al. (2009), Gassmann and Enkel (2004), Keupp and Gassmann (2009), Lichtenthaler (2008), Gianiodis et al. (2010), Barge-Gil (2010), Acha (2007), Huang et al. (2010), Laursen and Salter (2006), Duarte and Sarkar (2011), Christensen et al. (2005), Pavitt (1984), Von Hippel (1988), Lichtenthaler and Lichtenthaler (2009), and Robertson et al. (2012). Some of these articles classify open innovation along more than one dimension.

² As our data do not cover outbound movements of knowledge, we have omitted these from our typology.

³ In total, there were 4,269 innovative businesses (excluding five respondents in public administration). Of these, 10.3% or 441 did not answer at least one of the three questions (for product, process or organisational innovations) on how the innovation was developed.