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Understanding the Open Innovation Trends: An Exploratory Analysis of Breadth and Depth Decisions

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Abstract: The study of firms' decisions on open innovation has recently attracted the attention of scholars studying the process that firms follow from closed to open models. Extant research has acknowledged that firms tend toward open innovation models and has identified the optimum levels of breadth and depth of openness toward which firms should tend. Surprisingly, there is little evidence on how firms move toward open innovation and whether they follow scholars' recommendations. In this paper, we investigate the adoption of the open innovation model, studying firms' decisions on breadth and depth and switching behaviours over time. This paper provides a discussion of firms' degree of openness and how firms structure and reassess their decisions on open innovation over time. This framework was applied to the Panel of Technological Innovation database that includes data on Spanish innovating firms for the period 2005–2013.

Keywords: open innovation; breadth; depth; innovation strategies

1. Introduction

As competition intensifies, the advantages that firms gain from the sole use of internal research and development (R&D) investments are not sufficient. This fact forces firms to increasingly open up their innovation processes by combining internal and external knowledge (Dahlander and Gann 2010; Foss et al. 2011; Ferraris et al. 2018). Although innovation was traditionally based on internal and exclusive sources, now firms are adopting an open innovation model (Huizingh 2011), based on "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough 2003, p. 2).

As a result, the notion of open innovation has emerged as an underlying theme in research on innovation (Heimstädt and Reischauer 2019). One of the main assumptions of this stream of research is to consider innovation as a continuum between closed forms and opened forms of innovation, instead of a dichotomous decision. Along this continuum of innovation, firms could range from closed to open, covering different degrees of openness (Dahlander and Gann 2010; Huizingh 2011).

Based on this idea, one of the topics that have attracted the attention of scholars is the conceptualization of the degree of openness in terms of firms' breadth and depth in external knowledge search. On the one hand, the breadth of openness specifies to what extent firms access different external knowledge sources, including customers, suppliers, competitors and universities (Bahemia and Squire 2010; Leiponen and Helfat 2010). On the other hand, the depth of openness refers to how deeply or intensively firms draw from these different external knowledge sources (Laursen and Salter 2006; Drechsler and Natter 2012).

Over the last years, this line of research has focused on providing some insights into both components, particularly through the analysis of their impact on performance (Bahemia and Squire 2010; Inauen and Schenker-Wicki 2011; Parida et al. 2012; Ferraris et al. 2017). From the literature, it is clear that breadth and depth of openness provide potential advantages, such as uncertainty reduction, resource variety and higher technological opportunities (Laursen and Salter 2006; Huizingh 2011), which may allow firms to improve their innovation performance. However, scholars also find that there is a negative side in drawing broadly and/or deeply on external sources. On the one hand, obtaining information from too many and different external knowledge sources, to the extent that each of them involves different characteristics, requirements and rules (Laursen and Salter 2006; Dittrich and Duysters 2007), may lead firms to invest considerable efforts in managing the complexity of the information they obtain. On the other hand, a very deep search may produce redundant information (Katila and Ahuja 2002), leading to overlapping of firms' knowledge bases (Vanhaverbeke 2006). All these ideas may suggest that there is a point at which breadth and depth of openness become disadvantageous. In keeping with this idea, a number of recent contributions have tried to determine the optimum level of each of these two components, arguing that there should be an increasing trend on firms' open innovation decisions toward this specific level (Laursen and Salter 2006; Leiponen and Helfat 2010; Salge et al. 2013).

Against this background, it is surprising that there is a limited understanding of whether firms have been influenced by scholars' recommendations on breadth and depth optimum levels and the process that they follow in order to achieve these specific levels. Until now, scholars have analysed firms' breadth and depth decisions without verifying whether the optimum levels are being reached and without giving consideration to how firms organize their open innovation decisions over a time span (Drechsler and Natter 2012). That fact has prevented us from checking whether there exist a trend toward the optimum levels found by the literature and, therefore, it is not entirely clear to what extent firms take and modify their practices to adhere to scholars' guidelines about the optimum level of breadth and depth. Based on the lack of studies that may corroborate the relevance of previous findings offered by the open innovation literature, it seems that an analysis of both dimensions over a long time span is particularly needed. To the best of our knowledge, only three studies devoted their attention to the analysis of open innovation adoption over time (Batterink 2009; Poot et al. 2009; Cricelli et al. 2016). However, these studies do not pay attention on breadth and depth decisions and, therefore, do not determine whether firms reach the optimum levels proposed by the literature and how they do it.

To address this gap, in this paper we examine, over an extended period of time, the patterns of breadth and depth to find any kind of evidence of a tendency in firms' decisions about each of these components of open innovation. Although there is a sense that firms are opening their boundaries to external sources, there is little evidence that confirms that the levels of breadth and depth are increasing, or that describes the specific level to which firms tend. We analyse the patterns of breadth and depth by comparing firms' decisions about the use of external knowledge sources in each year of our sample, and secondly by determining how firms change their breadth and depth decisions over time.

We address this issue by using the Panel of Technological Innovation database (PITEC), which contains information about the innovative activity of Spanish firms. This database is especially useful for the purposes of this work, for two main reasons. First, it provides information about the type of partner from which firms are obtaining knowledge. With this information in mind, and following the logic of previous papers (see, for example, Belderbos et al. 2012), we are able to study firms' breadth and depth of openness. Second, the data provided by PITEC, in contrast to other innovation surveys, is administered on a yearly basis. Hence, the dataset has a longitudinal dimension, providing information about innovation variables from 2003 to 2013. That fact makes the data very suitable to analyse the changes that firms' breadth and depth decisions show over time.

Our contribution to the literature is twofold. First, we are able to analyse, over an extended period of time, the firm's tendency of breadth and depth. We do this by taking into account the sources of information according to their origin and over time. Until now, firms' decisions on breadth and depth

have not been examined over a time span, leading us to study firms' isolated decisions about the adoption of open innovation models, a fact that has prevented us from engaging in a discussion about open innovation integrally. Second, we investigate how firms' breadth and depth decisions change over time. This represents a significant advance over the analysis of breadth and depth of openness, which has been abstracted from studying the changes that firms' decisions on both components show over time.

2. Theoretical Framework

The open innovation model describes the recent trend in which firms look for new information and technologies for innovation outside their boundaries (West and Bogers 2017). The main idea behind this model is that the benefits that firms obtain through the isolated use of internal resources are decreasing, forcing firms to draw on knowledge from external sources (Dolfsma and van der Eijk 2017; Santoro et al. 2019). The origins of this idea can be found in those papers that study how firms tend to establish ties with external parties, such as customers, suppliers, competitors and universities (Hamel 1991; Atuahene-Gima 1995; Santoro 2000; Battistella and Nonino 2012). However, according to a seminal work by Chesbrough (2003), who established the basis for the open innovation model, it is argued that firms' innovation processes can and should be based on a combination of internal and external ideas and mechanisms to create value. In other words, the most important step of the open innovation model is to consider the innovation process as an open system (Laursen and Salter 2006).

Building on Chesbrough's proposal and taking as a starting point its broad nature, scholars have tried to deepen the open innovation model by defining openness in different ways (West and Bogers 2017; Bogers et al. 2017). For instance, a stream of the literature has focused on two dimensions, inbound and outbound, to define the activities that firms can develop when opening their boundaries (Gassmann and Enkel 2004; Cheng and Huizingh 2010; Bianchi et al. 2011; Rangus et al. 2016). Inbound open innovation refers to the process through which firms internally use the knowledge obtained from external sources, while outbound open innovation consists of the external use of the knowledge generated internally (Dahlander and Gann 2010; Santoro et al. 2019). In contrast, another line of research has defined the degree of openness of firms' external search processes, taking into account two different components: breadth and depth (Laursen and Salter 2006). Recent papers on open innovation have highlighted the importance of distinguishing between these two components since they capture two different external search strategies that show how firms organize themselves when deciding to open up their boundaries (Bahemia and Squire 2010). Since searching for external knowledge is the open innovation pattern most frequently used, an analysis of the different strategies through which firms search for new external ideas may constitute a key factor in exploring firms' movement toward open innovation (Laursen and Salter 2006). Therefore, it seems that to analyse firms' behaviour, taking into account both components may allow us to deepen and to integrally address the phenomenon of open innovation.

2.1. Breadth and Depth of Openness: Beneficial and Detrimental Effects

The literature has defined breadth as "the number of external sources or search channels that firms rely upon in their innovative activities" (Laursen and Salter 2006, p. 4). When studying the breadth of openness, several studies have emphasized its benefits. Specifically, scholars have argued that the most successful firms are those that search more broadly for knowledge, instead of looking for information narrowly (Ahuja and Lampert 2001; Ahuja and Katila 2004). The point is that, since innovation results are unclear due to turbulence and technological change, using various sources of knowledge in innovation processes can help firms in increasing the probability of maximizing their innovation outcomes. In the same vein, Tether (2002) argued that the higher cost derived from R&D and the evolution of technology make firms try to capture valuable resources by searching widely. Some researchers, such as Love et al. (2014), have demonstrated the positive effect on innovation performance that firms can obtain by increasing the different types of external sources that they use.

The underlying idea is that to search widely leads organizations to find a variety of resources that allows them to generate new combinations of knowledge and to access a rich range of technological opportunities (Laursen and Salter 2006).

Nevertheless, some studies, also recognizing the benefits of breadth, underline that there should be a limit when accessing different knowledge domains (Katila and Ahuja 2002). It has been argued that high levels of breadth can generate increasing cost of handling the integration of knowledge, even overcoming the benefits that it generates. On this basis, there is a stream of research recommending that firms concentrate their efforts on a limited number of external sources. Accordingly, Laursen and Salter (2006) have argued that to understand the norms and routines of a wide number of external knowledge sources, firms must dedicate considerable efforts, especially if they have to identify the ideas that they would like to absorb. In line with this idea, Laursen and Salter (2006) also pointed out that not all ideas come at the correct time to be exploited. Therefore, firms can be wasting energy having access to too many sources. In the same way, due to the high levels of breadth, firms cannot pay the required attention to some ideas that are really relevant. In a nutshell, some scholars have considered that, although breadth is positive, there is also a negative effect that should be taken into consideration. Based on these arguments, the literature has acknowledged that the relationship between breadth and innovation performance may show a non linear effect.

Taking this idea as starting point, researchers have gone a step further by determining the optimum level of breadth to which firms should tend. Specifically, Laursen and Salter (2006) found that firms maximize their performance using eleven sources of knowledge of the sixteen that they have available. That is, the optimum point can be found in the use of 68.75% of the sources available. Likewise, Leiponen and Helfat (2010) considered that the maximum return is obtained when using eight sources of a total of twelve, that is, in the use of 66.66% of the external knowledge sources. Meanwhile, Salge et al. (2013) indicated that, in order to maximize firms' results, the optimum level of breadth could be found in the use of six sources of external knowledge of a total of thirteen, that is, when using 46.15% of the external knowledge sources available.

For its part, depth is defined by the literature as "the extent to which firms draw deeply from the different external sources" (Laursen and Salter 2006, pp. 4–5). As in the case of breadth search, scholars have emphasized that drawing deeply from external sources is positive but can also have negative consequences. Maintaining a pattern of interaction with the external environment over time is understood to be positive since it allows firms to better understand the behaviour, habits and rules of the external knowledge sources. That fact allows firms to easily identify the valuable resources and to recombine them in different ways. In a similar vein, Katila and Ahuja (2002) argued that using the same resources repeatedly reduces the probability of error and enhances innovation. This, in turn, leads firms to learn how to access the information they need and to integrate it into their innovation process. Drawing knowledge heavily from external sources could also make firms become familiar with the knowledge they exchange, better identifying the activities that they develop. In this way, firms improve their efficiency, avoiding unnecessary steps (Eisenhardt and Tabrizi 1995; Katila and Ahuja 2002). Accordingly, scholars such as Laursen and Salter (2006) have demonstrated that firms focusing on a depth search will be more innovative, because they build long-lasting and secure relationships with their external environment.

However, drawing deeply on external ideas may require firms to invest substantial time and resources, a fact that negatively affects innovation performance (Laursen and Salter 2006; Lakhani et al. 2012). In addition, scholars have argued that using the same knowledge over time can result in overlapping. To ensure that the same knowledge will generate new ideas, firms must invest significant time and attention, which might not be worth such effort. To use the same knowledge during a long period of time can also generate rigidity problems (Katila and Ahuja 2002). Firms will try to solve problems based on their previous responses. However, because a strategy allowed a firm to get solutions does not mean that this approach should always be used. This can make firms focus on a strategy and then invest resources in it, even though it may not be appropriate (Laursen and Salter

2006). For all the reasons presented above, scholars have found a non linear relationship between depth and innovation performance.

As with breadth, scholars have tried to determine the optimum level of depth that allows firms to maximize their performance. Laursen and Salter (2006) concluded that firms should draw deeply on three sources of external knowledge, of the sixteen that they have available, in order to maximize their results. That is, the optimum point can be found in the deep use of 18.75% of the external sources available.

In such a context, in which the non linear effects of breadth and depth are generally accepted and the optimum levels of breadth and depth appear to be a much-debated topic, it is remarkable that there is little evidence on how the conclusions on these issues have influenced firms' trend on breadth and depth decisions. In other words, most of the literature has abstracted from analysing whether the confluence of positive and negative effects obtained and the optimum level of breadth and depth that scholars have found have conditioned firms' pattern of behaviour, which beforehand is unclear. Therefore, analysing to what extent firms' intensity on breadth and depth has changed over time seems to be necessary in order to avoid confusion around the adoption of open innovation strategies and to confirm the validity of the open innovation model (Chesbrough et al. 2006; Bianchi et al. 2011; West and Bogers 2017).

2.2. Breadth and Depth of Openness: Evidence on Their Adoption

Over the last years, researchers have consistently argued that firms are replacing their closed innovation models by open ones (Huston and Sakkab 2006; Bianchi et al. 2011). In reaching this conclusion, scholars have used different methods of analysis and have focused on specific industries, periods of analysis and countries.

In the seminal study of open innovation, Chesbrough (2003) used case studies to document how the business model of companies belonging to high-technology industries, such as IBM and Intel, has changed from closed to open forms. Subsequent research has confirmed this insight, also using case studies but applying them to other sectors. For instance, Dodgson et al. (2006) and Huston and Sakkab (2006) studied the specific case of Procter and Gamble, documenting how this firm develops open innovation practices. Gassmann (2006) conducted a case study of 15 companies in Germany, Liechtenstein, Switzerland, and The Netherlands that belong to different industries. Chesbrough and Crowther (2006) focused on the specific case of 12 companies that operate in "industries outside high technology that are early adopters of the concept." By studying firms' practices, they confirmed that open innovation practices are also present in more traditional and slow-growing industries, a fact that confirms the validity of the Open Innovation model. Regarding the financial service industry, Fasnacht (2009), by studying the case of 18 firms belonging to this sector, identified a shift from closed to open models.

While case studies are common when analysing open innovation adoption trends, some researchers have longitudinal data to analyse firms' behaviour. Such is the case of Van de Vrande et al. (2009), who used data from 605 Dutch companies to document the adoption of open innovation in small and medium-sized enterprises (SMEs), confirming the firms' trend toward the use of external knowledge sources. Salmi et al. (2008) focused on 59 Finnish firms to conclude that open innovation practices are present although they are still low. Poot et al. (2009) incorporated a longitudinal perspective in the analysis of the adoption of open innovation practices using the Dutch Community Innovation Survey. More recently, Bianchi et al. (2011) explored firms' intensity on open innovation in a sample of 20 companies belonging to the biopharmaceutical industry, by distinguishing between inbound and outbound dimensions.

Besides these limited contributions, scholars have not systematically studied the adoption of open innovation models by taking into account firms' degree of openness. Researchers studied firms' trend toward open innovation but without a detailed specification on firms' decisions, although this would allow us to better understand the intensity of the adoption of open innovation models. As Chiaroni et

al. (2011) have argued, "understanding the anatomy of the process from closed to open innovation requires identification of the dimensions along which change occurs." In this sense, the analysis of firms' breadth and depth of openness can help us understand the specific actions that open innovation firms have taken. This paper contributes to fill this gap by analysing how firms' breadth and depth evolve over time.

3. Data and Descriptives

3.1. Sample

Our empirical analysis is based on the Technological Innovation Panel database (PITEC). The database has been developed by the National Institute of Statistics (INE), with the support of the Spanish Foundation for Science and Technology (FECYT) and the Spanish Foundation for Technological Innovation (COTEC). The structure of PITEC is based on the Community Innovation Survey (CIS) framework, which in turn follows the guidelines of the Oslo Manual (OECD 2005).[1] PITEC is a panel data survey that provides annual information about the innovative behaviour of a large sample of Spanish firms from 2003 and has been previously used for several purposes (Fariñas and López 2007; Molero and Garcia 2008; De Marchi 2012).

PITEC has two main advantages for this study. First and most important, the PITEC questionnaire (Appendix A), in contrast to the majority of work on open innovation, is administered on a yearly basis. This implies that our analysis will provide information about the innovative activity of Spanish firms for an extended period of time. Second, the survey contains information about firms' decisions on knowledge sourcing. Specifically, the data include the type of information sources to which firms have access, which is necessary to analyse breadth and depth.

From these data we used information for the period 2005 to 2013. We selected our final sample by following three steps. First, we restricted our sample to firms engaging in innovative activities (Laursen and Salter 2006).[2] Second, we focused our analysis on manufacturing and service firms. Third, we excluded those firms with no information for the main variables, those that have suffered problems associated with mergers and acquisitions, and those that are public or newly created. This means that we were left with 57,984 observations.

Table 1 shows the distribution of the firms depending on size.[3] As can be seen, about 40% of companies have between 10 and 49 employees (small enterprises), closely followed by medium enterprises (around 32% of the sample).

Table 1. Firms by size.

	N	%
Micro-enterprises	5761	9.94
Small enterprises	23,129	39.89
Medium enterprises	18,358	31.66
Large enterprises	10,736	18.51
Total	57,984	100.00

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1. The data set, the questionnaire, and the description of each variable is available at: http://icono.fecyt.es/PITEC/Paginas/por_que.aspx. In order to prevent firms from being identified, some variables are anonymised. López (2011) shows that the expected biases due to this anonymisation are small through the comparison of regressions that use original and harmonized data alternatively.
2. Innovators are those firms that have developed product or process innovation and those that have attempted it and have failed in doing so.
3. Classification made according to the criteria established by the European Commission Regulation (CE) No 800/2008 of 6 August 2008 (DOUE L214/3 of 9 August 2008), which defines the requirements for three categories of companies: microenterprises, comprising those that employ fewer than 10 workers; small businesses which includes those that employ 10 to 49 workers; and medium enterprises, comprising those that employ between 50 and 249 workers.

Similarly, Table 2 shows the distribution of the firms according to their main activity.

Table 2. Firms by activity.

	N	%
Manufacturing	36,468	62.89
Services	21,516	37.11
Total	57,984	100.00

3.2. Variables

Breadth and depth are the variables in this study. Both variables are constructed as a combination of eleven sources of knowledge for innovation. These information sources are: firms that are part of the same group, suppliers, customers, competitors, consulting companies, universities, the public sector, technological centers, conferences, journals and professional associations.

Regarding breadth, and in line with Laursen and Salter (2006), each of the eleven sources is coded as a binary variable that takes the value 0 if the firm has indicated that this source of information is not used, and 1 if the source is used. After that, the eleven sources are added up and, by doing this, the variable takes the value of 0 when no knowledge sources are used and 11 when all sources are used. Therefore, firms that use a higher number of sources are more open in terms of breadth.

To construct our depth variable, and also in line with Laursen and Salter (2006), each of the eleven sources takes the value 1 if the firm indicates that it uses the source to a high degree and 0 in the case of low, medium, or no use of the given source. In a similar way as in the case of breadth, the eleven sources are added up so the variable takes the value of 0 when no knowledge sources are used to a high degree and 11 when all sources are used to a high degree. Again, firms that obtain higher values are those that are more open in terms of depth.

4. Results

In order to analyse in some detail the patterns of firms' decisions about the use of external knowledge sources, we compare the distribution of firms in different degrees of breadth and depth across each year of our sample. Descriptive data for observations of firms' breadth decisions are shown in Table 3.

Table 3. Proportions of sample in each level of breadth of openness by time period.

Breadth	2005–2013 (No)	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	4.03 (2339)	0.03	0.35	0.24	4.12	8.81	8.76	5.81	5.07	5.26
1	8.06 (4671)	8.07	9.98	10.79	8.56	6.42	7.29	6.76	6.89	6.25
2	5.34 (3099)	5.70	5.9	6.21	5.44	4.90	4.11	4.8	5.34	5.41
3	5.22 (3025)	6.28	5.88	5.47	4.90	4.69	4.67	4.85	4.97	4.8
4	5.95 (3449)	7.28	6.63	6.35	5.38	5.33	5.39	5.36	5.63	5.73
5	7.32 (4243)	8.97	7.75	7.39	7.34	7.07	6.87	6.38	6.38	6.99
6	7.61 (4414)	8.5	7.91	8.15	8.22	7.58	6.82	6.94	6.96	6.63
7	8.92 (5172)	10.34	9.51	9.42	8.98	8.75	8.35	8.42	8.24	7.26
8	9.98 (5784)	10.73	10.66	10.43	10.34	9.68	9.77	9.79	8.76	8.72
9	7.25 (4206)	7.44	7.29	7.17	6.92	7.22	6.85	7.07	7.68	7.88
10	6.95 (4028)	6.31	6.32	6.54	7.12	7.48	7.35	7.83	6.93	6.97
11	23.38 (13,554)	20.35	21.83	21.83	22.68	22.07	23.77	25.99	27.14	28.09

As can be seen in the table, and focusing on the results of the entire period, firms tend to get medium and high levels of breadth. Around 23% of firms in our sample use the eleven sources of innovation that are available to them, approximately 8% have access to six sources, and only 4% indicate that zero knowledge sources are used. Table 4 shows the descriptive data for firms' depth decisions.

Table 4. Proportions of sample in each level of depth of openness by time period.

Depth	2005–2013 (No)	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	23.35 (13,542)	20.69	22.09	23.32	25.15	26.49	27.25	22.27	21.22	0.66
1	30.80 (17,861)	32.94	32.33	30.93	29.94	28.43	28.99	31.58	31.15	30.76
2	20.73 (12,020)	21.65	21.57	21.03	20.48	20.76	19.30	20.31	20.08	20.99
3	12.18 (7061)	12.57	11.85	12.11	12.27	11.91	11.63	12.01	12.88	12.61
4	6.16 (3571)	5.95	6.14	6.34	5.72	5.78	5.9	6.47	6.6	6.95
5	3.34 (1939)	3.13	3.1	3.06	3.24	3.25	3.57	3.68	3.54	3.87
6	1.66 (961)	1.62	1.5	1.58	1.44	1.67	1.59	1.73	2.28	1.73
7	0.88 (513)	0.69	0.69	0.82	0.91	0.87	0.77	1.17	1.12	1.14
8	0.46 (267)	0.43	0.37	0.47	0.43	0.43	0.46	0.38	0.58	0.67
9	0.21 (122)	0.12	0.17	0.17	0.27	0.25	0.29	0.18	0.21	0.25
10	0.07 (38)	0.01	0.03	0.03	0.03	0.09	0.06	0.09	0.14	0.19
11	0.15 (89)	0.2	0.15	0.17	0.13	0.07	0.18	0.13	0.19	0.17

Unlike what happens in the case of breadth, firms tend to have low levels of depth. Approximately 30% of firms deeply focus on one source of knowledge, and 23% indicate that no knowledge sources are used to a high degree. About 2% of firms have deep access to six sources of knowledge, and only about 0.15% of firms intensively draw from the eleven sources of knowledge for which they are asked. Tables 3 and 4 also show the tendency of firms' breadth and depth decisions over time. As can be seen in Table 3, there is slight evidence of an increase of the percentage of firms focusing on eleven sources of knowledge, and a decrease in the case of firms using one or zero sources of knowledge. Regarding the changes in firms' depth decisions, Table 4 shows that, during the period of analysis, there is a modest increase of the percentage of firms in each category of depth, followed by a moderate decrease.

In addition to the above, we investigate how firms' breadth and depth decisions change over time using a transition matrix (see Tables 5 and 6) that presents some data that will guide us in explaining the evolution of both constructs from 2005 to 2013. This matrix shows the switching behaviour of firms between different levels of breadth and depth, allowing us to examine whether there is any systematic change in firms' decisions on open innovation over time.

Table 5. Transition matrix of breadth of openness.

Starting Category	End Category											
	0	1	2	3	4	5	6	7	8	9	10	11
0	30.93	13.77	6.91	5.13	5.95	5.73	4.34	5.13	4.95	2.95	2.48	11.73
1	2.76	41.08	7.9	5.38	5.43	5.75	4.72	5.51	4.56	2.41	2.17	12.32
2	2.01	11.05	40	6.9	6.27	6.31	4.42	3.94	4.34	2.37	1.89	10.49
3	1.61	8.28	7.87	42.5	7.13	6.34	5.31	4.2	4.41	2.39	2.1	7.87
4	1.62	6.61	5.43	7.26	44.36	8.81	5.39	4.78	4.28	2.26	1.91	7.3
5	1.59	5.49	3.38	5.17	8.03	46.26	7.51	5.83	4.56	2.34	2.28	7.57
6	1.18	3.54	2.44	3.18	5.1	8.61	50.49	8.17	5.87	2.47	2.17	6.77
7	0.91	3.06	2.01	2.78	3.15	5	8.47	51.91	8.99	4.18	2.73	6.82
8	0.82	2.72	2.02	2.02	2.02	3.52	5.03	9.69	53.79	6.16	3.44	8.76
9	0.64	2.16	1.46	1.37	1.49	2.52	3.19	5.97	10.79	52.59	6.92	10.9
10	0.43	2.19	1.33	1.04	1.47	1.38	2.28	3.8	5.99	9.37	52.51	18.21
11	1	3.36	2.01	2.03	1.79	2.38	2.3	3.06	4.42	4.03	6.1	67.53

Table 6. Transition matrix of depth of openness.

Starting Category	End Category											
	0	1	2	3	4	5	6	7	8	9	10	11
0	58.88	20.58	10.95	4.81	2.45	1.14	0.61	0.31	0.10	0.03	0.01	0.12
1	13.34	66.35	11.51	4.96	2.11	0.95	0.38	0.22	0.09	0.03	0	0.05
2	9.25	17.61	59.62	7.92	3.26	1.26	0.54	0.27	0.17	0.03	0.01	0.08
3	7.61	11	14.65	56.7	6.1	2.4	0.69	0.42	0.22	0.07	0.03	0.12
4	6.83	10.29	10.16	13.53	50.74	5.08	2.14	0.66	0.3	0.03	0.10	0.13
5	5.75	8.51	8.15	9.29	10.19	50.81	4.31	1.68	0.6	0.42	0.18	0.12
6	6.94	7.43	5.72	6.21	7.43	10.48	50.3	3.17	1.34	0.49	0	0.49
7	7.54	5.32	7.54	5.10	4.66	6.43	9.76	46.78	4.21	1.55	0.67	0.44
8	5.31	6.19	5.31	7.08	6.19	5.75	5.31	7.96	43.81	5.75	0	1.33
9	5.50	3.67	3.67	5.50	2.75	5.50	4.59	6.42	11.01	50.46	0	0.92
10	8.33	0	5.56	11.11	2.78	8.33	13.89	5.56	2.78	2.78	38.89	0
11	10.61	19.7	10.61	4.55	7.58	1.52	3.03	1.52	6.06	0	0	34.85

The transition matrix in Table 5 shows that maintaining the level of breadth is the most common pattern of behaviour, especially for firms that use a high number of sources.

As can be seen, the main diagonal, that represents a sustained behaviour in terms of breadth decisions, presents the highest percentages. For instance, 30.93% of firms that indicate that no knowledge sources are used continue using zero sources. Around 50% of the firms that start with an intermediate level of breadth stay within their original category. Nevertheless, the number of companies that continue at their starting level of breadth is especially high for those firms that use the highest number of external knowledge sources, that is, eleven. Specifically, 67.53% of firms maintained the maximum level of breadth over time. The data in Table 5 also show evidence of switching behaviours, although they are in a minority. The changes, generally, are undertaken toward high levels of breadth. This is most notable for firms that are first observed in very low or very high levels of breadth. It means that, although firms tend to maintain their levels of openness, in terms of breadth, firms that switch tend to focus on using a high number of sources. This can represent a radical change for those firms that at the beginning do not use any source of knowledge. This is the case for around 12% of firms that are first observed in the group that indicates that no knowledge sources are used and then decide to use eleven sources of knowledge. In contrast, it represents a small increase for those firms that start with high but not maximum levels of breadth. Specifically, around 18% of firms increase their level of breadth one point, to reach the highest levels. Firms that start with intermediate levels of breadth tend to maintain their levels, especially switching to the lowest levels.

It should be noted that if we distinguish between high-technology sectors and low-technology sectors, the pattern that can be observed is very similar, even though there is an interesting difference[4]. For low-technology sectors, the proportion of firms that indicate that, at the beginning, no knowledge sources are used and maintain their strategy is higher compared to high-tech firms. Additionally, the proportion of firms that use eleven sources of knowledge and stay within their original category is lower than with high-technology firms. This result may mean that the trend of low-tech firms points toward a lower level of breadth.

When analysing firms' breadth decisions, it might be interesting to take into account the optimum level of breadth that previous papers have found as the point to which open innovation firms tend to focus. As indicated before, Laursen and Salter (2006) found the optimum level at the use of 68.75% of sources available, Leiponen and Helfat (2010) found that firms can reach this optimum level at the use of 66.66% of sources that are available and Salge et al. (2013) found it at the use of 46.15% of the external knowledge sources available. If we calculate the average of these percentages, the overall

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[4]   These analyses are not included due to their length, but they are available upon request.

conclusion is that the optimal decision for firms would be the use of around 61% of the sources of external knowledge that are available to them, in relative terms (Laursen and Salter 2006; Leiponen and Helfat 2010; Salge et al. 2013). If we apply this idea to our data, it corresponds to the use of seven sources of external knowledge. Focusing on Table 3, and more specifically on the results of the entire period, we could say that approximately 9% of the firms studied reach this optimum level of breadth, since they use seven sources of external knowledge. Focusing on the transition matrix in Table 5, we can study whether firms tend to maintain this optimum level of breadth, according to previous research. As can be seen, approximately 52% of the firms that use seven sources of external knowledge decide to continue at the same level. The transition matrix also shows switching behaviours toward this level of breadth. Around 5% of firms that start at any level of breadth tend to use seven sources of knowledge. It is remarkable that this percentage is slightly higher in the case of firms that start being very close to the use of the optimum number of sources. In this case, around 9% of firms end up using seven external knowledge sources, achieving the optimum according to previous research.

The transition matrix shown in Table 6 also demonstrates that remaining at the starting level of depth is the most common conduct, as reflected in the data of the main diagonal of the table, especially for firms that indicate that no knowledge sources are used to a high degree.

As can be observed, 58.88% of firms that at the beginning do not draw deeply on any source kept up their behaviour. Just like in the case of breadth, around 50% of firms with medium levels of depth decided to remain in these categories. However, in this case, firms that tend to further deepen are less likely to maintain their positions. For instance, around 35% of firms maintained the maximum level of depth over time. In this case, switching firms tend to choose lower levels of depth. This trend is particularly observed in the case of firms that first focused on drawing deeply on a high number of sources. However, firms do not make sudden changes, in contrast to what occurs in the case of breadth, and tend to focus on low but not minimal levels of depth. This is the case for 40% of firms that are first observed as firms that use a high number of sources to a high degree and decide to focus on intermediate levels of depth to a high degree.

Once again, we can find some differences if we split the sample into high- and low-tech industries[5]. For low-tech sectors, the proportion of firms that indicate that at the beginning no external knowledge sources are used to a high degree and remain in this category is higher compared to high-tech firms. In addition, the proportion of firms that were first observed in the group that uses eleven sources of external knowledge to a high degree and stay there is lower than in the case of high-technology firms.

With respect to the optimum level of depth, and as indicated before, Laursen and Salter (2006) found that the optimum decision is to use 18.75% of the external sources available to a high degree (Laursen and Salter 2006). If we apply this to our data, it corresponds to the use of two sources of external knowledge. Taking into account this idea and focusing on the results of the entire period that Table 4 offers, it could be said that around 21% of the firms in our sample reach this level, in relative terms. By analysing the transition matrix in Table 6, we can see whether firms decide to maintain this optimum level of depth, according to Laursen and Salter (2006). As can be observed, approximately 60% of the firms that use two sources of external knowledge to a high degree decide to maintain their behaviour. If we focus on the switching behaviours, Table 6 shows that there are differences depending on the starting category of firms. Firms that are first observed using low and medium levels of depth are more likely to reach the optimum level of depth. For instance, around 11% of firms start by indicating that they are not using knowledge sources to a high degree end up reaching the optimum level of depth. In contrast, around 5% of firms that initially use a high number of sources to a high degree finally focus on the optimum level of depth, except in the case of firms that start using the maximum number of sources available to a high degree. In this case, the 11% of firms end up using two of the external knowledge sources that are available to them.

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5   These analyses are not included due to their length, but they are available upon request.

5. Discussion and Conclusions

The purpose of this paper was to examine firms' patterns of breadth and depth in order to identify whether there is a trend on open innovation decisions over time. Prior research has provided some insights on breadth and depth decisions, for example, by indicating the optimum level to which firms should tend. However, so far, the literature has devoted little attention to the analysis of firms' tendency on breadth and depth over a time span, a fact that has prevented us from checking on whether there is an increasing tendency on firms' open innovation decisions toward this specific level. Our paper addressed this gap by studying firms' pattern of behaviour over an extended period of time, using the Technological Innovation Panel data set, covering the period 2005–2013.

The results of this study support the idea that firms are increasingly adopting open innovation models, although firms tend to be more open in terms of breadth than in terms of depth. Our analysis shows that the firms in our sample tend to get medium and high levels of breadth and that they maintain their initial level over time. This trend is especially found for those firms that have access to the highest number of external knowledge sources, that is, eleven. This demonstrates that firms that have high levels of breadth found benefits through the use of external knowledge sources, deciding to maintain their behaviour. In addition, firms have gradually modified their innovation decisions towards high levels of breadth, thus supporting the idea that firms tend toward open innovation models (Drechsler and Natter 2012; Barge-Gil 2013). The same results can be found if we split the sample between high-technology and low-technology sectors, although low-tech firms tend to focus on a slightly lower level of breadth. If we focus on the optimum level of breadth obtained by previous studies, we find that around 5% of firms that start at any level of breadth reach this level. Therefore, we have not found a general trend toward this specific level.

Regarding depth decisions, firms tend to have deep access to a low number of sources of knowledge. In addition, they tend to remain at their starting level, especially those firms that do not use any source of knowledge to a high degree. In contrast, firms that further deepen are less likely to maintain their initial pattern. In addition, it should be noted that firms that switch tend to choose lower levels of depth, especially firms that draw deeply on a high number of sources. That fact demonstrates that, in contrast to what happens with breadth decisions, the Open Innovation model is not completely supported in terms of depth. In addition, if we divide our sample by taking into account the technological intensity, we reach the same conclusions, although the patterns are more pronounced in the case of low-tech sectors. Focusing on the optimum level of depth determined by previous studies, firms that indicate that they are not using knowledge sources to a high degree are more likely to reach these levels compared with firms that initially use a high number of sources to a high degree. Nevertheless, our data do not provide evidence that firms tend to the optimum level of depth.

Our paper aims to contribute to the open innovation literature in two ways. First, we analyse firm's tendency of breadth and depth over an extended period of time. Until now, previous papers have analysed breadth and depth of openness abstracting from studying both components over a time span, a fact that has prevented us from checking whether there is a trend toward open innovation models, as the literature has argued (Drechsler and Natter 2012). In this regard, we use the data from Spanish firms, included in the Technological Innovation Panel database (PITEC), which is an appropriate tool for studying firms' behaviour over extended periods of time. Second, our analysis shows how firms' decisions on both components change over time. By doing this, we are able to study how firms structure and reassess their breadth and depth decisions over time and whether firms tend to the optimum level pointed out by previous studies (Laursen and Salter 2006). The main contribution of the paper is the analysis of the way at which firms reconsider their decisions on open innovation through time. The majority of previous studies have not focused on changing behaviours, thus not providing guidance for firms on how they can move toward the optimum levels of breadth and depth recommended by the literature. Therefore, by examining how firms' trend on breadth and depth decisions over time we are able to provide a more nuanced picture of the phenomenon.

5.1. Practical Contributions

Our study also offers several implications for business practitioners. By offering insights into the two components of openness, breadth and depth, we provide managers with a helpful and a more nuanced picture of the phenomenon through which they could observe, in a detailed manner, the decisions that firms make. In addition, as we demonstrate, each component of openness behaves differently, so practitioners need to pay attention to all the components when trying to innovate. Previous studies have demonstrated that each component has a different optimum level (Laursen and Salter 2006), so considering open innovation without taking into account its multifaceted character may prevent managers from making appropriate decisions. Based on our results, this study will allow practitioners to know that few firms reach the optimum level of breadth that scholars recommend. The majority of firms tend to use a higher number of external knowledge sources, a fact that previous studies have demonstrated to be detrimental in terms of innovation performance. This may highlight an erroneous belief that some managers have regarding open innovation decisions. On the other hand, practitioners will be aware that a greater proportion of firms are reaching the optimum level of depth proposed by the literature. However, they will also know that, frequently and incorrectly, a large number of firms decide not to draw deeply on any external source. These firms will then know that they are overlooking the significant benefits that a deep search may have. However, managers need to be aware that, when making decisions about breadth and depth of openness, there are other factors that should be taken under consideration, such as the industry in which firms operate and the type of product or service that are developing. These factors, besides the number of external sources that firms decide to use, will condition innovation performance.

5.2. Limitations and Future Research

In spite of the contribution of our paper, several issues may require additional attention. Since our paper has an exploratory nature, it would be interesting to test whether the decisions that firms take affect innovation performance. It would allow firms to know to what extent their decisions on breadth and depth do not meet their objectives. Moreover, in addition to investigating firms' breadth and depth, it would be useful to identify the type of knowledge that firms access. This would provide a more nuanced picture about firms' tendencies over time. Furthermore, it could be interesting to investigate whether and how firms from other countries show the same pattern of behaviour on breadth and depth. Until now, investigations using data from other countries have mostly studied open innovation without taking into account the breadth and depth components. Checking whether this phenomenon occurs in different scenarios may allow us to generalize our results.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A Variable Description According to the Original Questionnaire

Sources of information for technological innovation activities during the period 200X–20XX.

During the period 200X–20XX: Which has been the relevance of each of these sources of information for your innovation activities?

	Source of information	Importance level			
		High	Intermediate	Reduced	Not used
Internal	Inside the firm or group of firms				
Market sources	Suppliers				
	Customers				
	Competitors				
	Consultants, commercial laboratories or R&D private institutes				
Institutional sources	Universities				
	Public research organizations				
	Technological centers				
Other sources	Conferences				
	Journals, technical and commercial publications				
	Professional associations				

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