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What drives biopharmaceutical firms' exploratory openness? A comparative process tracing approach to the analysis of R&D microfoundations

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ABSTRACT

By responding to the call for a multidimensional approach in the open innovation domain, the present work aims to clarify the interplay of different internal R&D resources as microfoundations through which exploratory openness is encouraged and enacted.

By combining the use of fuzzy- set qualitative comparative analysis (fsQCA) and process tracing, we undertake an in-depth analysis of specific causal mechanisms, linking a combination of internal R&D resources to predicting biopharmaceutical exploratory openness. In line with the theoretical framework, the breadth and depth of the firm knowledge base were translated into three different sources of diversity, which represent the three fsQCA conditions: R&D team composition, corporate research relationships, and R&D resource allocation.

The study reveals that diversity in R&D resources contributes in a multifaceted way to firms' exploratory openness and is determined by the interactions among different dimensions of diversity.

1. Introduction

Since the seminal work of Chesbrough (2003), cited cases and evidence from the pharmaceutical industry have been widely used to illustrate and develop the open innovation (OI) framework (Gassmann & Reepmeyer, 2005; Rothaermel, 2001; Schuhmacher, Gassmann, McCracken, & Hinder, 2018; Schuhmacher, Germann, Trill, & Gassmann, 2013). In the emerging biopharmaceutical industry (biopharma), the characteristics of technologies, their complexity, and multi-sectoral market responsiveness have led these firms to a completely new approach to innovation (Aamir et al., 2014). Indeed, the extensive use of technological collaborations has been demonstrated to be a vital factor in all the different phases of pipeline development, including discovering opportunities, testing ideas, and gathering resources for market innovation (Bianchi, Cavaliere, Chiaroni, Frattini, & Chiesa, 2011; Bianchi, Croce, Dell'Era, Di Benedetto, & Frattini, 2016; Hunter, 2014; Lo Nigro, Morreale, & Gianluca, 2014).

Many studies in the field focus on OI practices, tied to a company's research and development (R&D) strategy (Henkel, Schöberl, & Alexy, 2014; Schuhmacher et al., 2013; Schuhmacher et al., 2018), and the literature empirically investigates biopharmaceutical openness by distinguishing between technology exploration (i.e. activities to acquire new knowledge and technologies) and exploitation (i.e. practices to improve profit from internal knowledge) (Bianchi et al., 2016; Xia & Roper, 2016). Exploratory relationships are the most diffused in biopharma and form the predominant content of R&D efforts (Schroll & Mild, 2011; Xia & Roper, 2016).

Scholars refer to different OI practices as inbound and outbound (Chesbrough & Bogers, 2014), and some authors have argued that these two types of practices are based on different patterns of inter-organisational knowledge flows, which facilitate various forms of innovation (Xia & Roper, 2016).

These studies agree with one of the assumptions of the OI paradigm – that internal knowledge resources are the root of a firm's absorptive capacity (Cassiman & Veugelers, 2006; Zahra & George, 2002) needed to identify and acquire external knowledge (Xia & Roper, 2016). In fact, the emerging debate demonstrates that biopharma companies develop several OI practices from their specific internal knowledge resources (Soh & Subramanian, 2014; Xia, 2013).

Among these practices, open search represents a high learning activity requiring diverse knowledge resources (Laursen & Salter, 2006) and influences a variety of OI activities (Chesbrough & Bogers, 2014). Moreover, at the exploratory open level, internal R&D resources become immediately relevant. Exploratory search gives a firm access to external knowledge with diversity and heterogeneity. It simultaneously increases the risks of experiments and cross-validation with internal knowledge (Chiang & Hung, 2010; Schroll & Mild, 2011) because exploratory openness is characterised by very dissimilar requirements

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regarding the level of investments and uncertainty and is necessary for exploring new knowledge rather than exploiting existing knowledge (Enkel & Heil, 2014; Xia & Roper, 2016). Moreover, the collaboration with external R&D partners could be highly risky and costly due to intellectual property infringement, lack of appropriate skills, or merely the effect of the well-known "not invented here" syndrome (Schuhmacher et al., 2018).

Even though the role of internal resources in the OI paradigm has been studied (Lichtenthaler, 2011) and the performance effects of an open search strategy have been well examined (Chiang & Hung, 2010; Laursen & Salter, 2006), the relationship between internal R&D resources and the different practices of the OI process remain unexplored. There are a few empirical studies investigating the drivers of the open R&D exploratory activities, and these contributions have emphasised some external factors, such as the breadth and depth of the relationships (Laursen & Salter, 2006), the characteristics of partners or innovation activities (Bengtsson et al., 2015), and competitive pressures (Cheng & Huizingh, 2014). Some studies also consider a number of diverse internal R&D resources that spur this externalisation, such as R&D expenditures (Huang, Lin, Wua, & Yu, 2015), human capital (Bogers, Foss, & Lyngsie, 2018; Escribano, Fosfuri, & Tribó, 2009), and organisational competences (Schroll & Mild, 2011). Unfortunately, these studies focus on only one factor at a time and mostly treat organisations as a whole as the main research subject.

Recently, some scholars debating firms' struggles with exploratory openness have argued for a microfoundations view (Ahn, Minshall, & Mortara, 2017; Bogers et al., 2018; Lowik, Kraaijenbrink, & Groen, 2017; Vanhaverbeke & Cloodt, 2014), which is consistent with Felin, Foss, Heimeriks, and Madsen (2012) who stress the role of individuals, processes, and structures of companies to understand the creation and development of innovation management and capabilities (Felin, Foss, & Ployhart, 2015).

However, studies on microfoundations are still emergent, and they do not capture the different aspects of R&D resources for exploratory openness tasks. Specifically, they tend to focus on one single factor at a time, so they are not sensitive to the interdependent roles that different R&D resources play (Iannacci & Cornford, 2017). By responding to the call for a multidimensional approach in the OI domain (Bogers et al., 2017), the present work aims to clarify the interplay of different internal R&D resources as microfoundations through which exploratory openness is encouraged and enacted.

By combining fuzzy-set qualitative comparative analysis (fsQCA) and process tracing, we undertake an in-depth analysis of specific causal mechanisms, linking a combination of internal R&D resources to predicting biopharmaceutical exploratory openness. This study seeks to contribute to the literature in three important ways. First, it contributes to the OI literature by developing a framework for the examination of microfoundations of exploratory openness. Inspired by Bogers et al. (2018), the diversity of internal R&D resources as predictors of exploratory openness has been analysed across three microfoundations dimensions: organisational (Bogers et al., 2018), corporate (Ahn et al., 2017), and strategic (Bogers et al., 2017). Second, this study can contribute to the existing literature on OI practices in biopharma by proving that the diversity of R&D resource allocation emerges as a specific strategic aspect of companies' research strategies when the focus is on microfoundations of exploratory openness. Third, the study offers a methodological contribution because, to the best of our knowledge, it is one of the few attempts to use a multi-method approach in innovation studies. In fact, owing to its potential to unveil the combinatory effects of several attributes, this approach of combining fsQCA and process tracing is particularly fitting to the research question, which is connected to the multidimensional nature of R&D resources at the basis of exploratory openness.

The remainder of this paper is structured as follows. The next section illustrates the main theoretical issues and the framework used to analyse the links between a firm's internal R&D resources and exploratory openness. The methodological section details the steps of the comparative process tracing procedure, followed by a summary of the empirical results. The discussions and implications sections conclude the paper.

2. Conceptual background and framework

Studies in the OI field provide a comprehensive theoretical and empirical explanation of the connection between internal knowledge resources and OI via absorptive capacity (Cassiman & Veugelers, 2006). More recently, the debate has grown to address the multidimensionality of OI drivers (Bogers et al., 2017; Distel, 2017).

Within this framework, the debate on the breadth and depth of internal R&D activities has assumed a crucial role in leading internal knowledge processes toward open exploration for innovation (Bengtsson et al., 2015; Linn & Wu, 2010; West & Bogers, 2014). One of its effects has been to promote more risk-taking tasks and exploration of open activities that can be far removed from a company's existing knowledge bases or technologies (Vanhaverbeke & Cloodt, 2014). More R&D resources available internally support open search, as they can contribute to optimising OI collaboration, sharing knowledge, and introducing new technologies (Vanhaverbeke & Cloodt, 2014; West & Bogers, 2014).

A few recent studies that examine firms' struggles with open search have claimed that it is necessary to analyse individual-level attributes involving both human and organisational mechanisms (Lichtenthaler, 2011). The microfoundations approach has recently emerged as useful for understanding the underlying mechanisms of a firm's abilities to absorb new knowledge completely. For example, Bogers et al. (2018) discuss the microfoundations view at the employee level and theorised how diversity in employees' skills affect openness to external knowledge sources. Knowledge diversity as an R&D microfoundation also concerns companies' domain-specific knowledge repertoire and their propensity to search more broadly for new knowledge in unfamiliar research and technology areas (Lowik et al., 2017). From a different perspective, Ahn et al. (2017) demonstrate the influence of Chief Executive Officers (CEOs) on open R&D strategies in small and medium firms, directing attention to strategic leadership and the human element.

Owing to the complexity of R&D in the biopharma (Aamir et al., 2014; Xia, 2013), it seems important to analyse in-depth the diversity of R&D resources and how their interactions influence exploratory openness as microfoundations aspects. The literature in the OI field and biopharma has addressed different aspects of R&D resource diversity, which also measures the breadth and depth of a firm's knowledge base. Building on this literature, we discuss R&D diversity as it concerns different factors, including R&D team composition, corporate research relationships, and R&D resource allocation (see Table 1).

2.1. Diversity of R&D team composition

R&D team diversity represents a distinct set of the microfoundations regarding human capital and organisational characteristics. First, West, Vanhaverbeke, and Chesbrough (2006) and Zhang et al. (2007) discuss diversity in the knowledge backgrounds of R&D employees as a critical success factor in the assimilation of new knowledge. The diversity of human capital has recently emerged as a promising factor in understanding the underlying mechanisms of an effective OI approach. By proposing the concept of diversity, Bogers et al. (2018) demonstrated the synergistic role of employees' work history and educational background in predicting open practices. Broad knowledge-based skills facilitate the identification, acquisition, understanding, and integration of new external knowledge into internal operations in critical fields as well as the detection of potential technological changes (Lowik et al., 2017; Salter et al., 2015). As this last feature represents a key resource in the open search innovation of biopharma (Xia & Roper, 2016), the

Table 1
Characteristics of R&D resources and open innovation literature.

Categories	Topics	Main authors	Microfoundations aspects
R&D team composition	- diversity of human capital knowledge and capabilities - diversity in employees' education	West et al. (2006); Zhang, Baden-Fuller, and Mangematin (2007); Salter, Ter Wal, Criscuolo, & Alexy, 2015; Bianchi et al., 2016; Lowik et al., 2017; Bogers et al., 2018	Human capital and employee aspects/organisational aspects
Corporate research relationships	- Science-based origin of firms - corporate research network - entrepreneurship background	Bianchi et al., 2011; Soh & Subramanian, 2014; Rasmussen & Clausen, 2012; West, Salter, Vanhaverbeke, & Chesbrough, 2014; Ahn et al., 2017	Human and governance dimensions/corporate aspects
R&D resource allocation	- Firm's knowledge breath - diversity of knowledge base between internal and external knowledge	Grimpe & Sofka, 2009; Schroll & Mild, 2011; Xia, 2013, Cheng & Huizingh, 2014, Hosseini, Kees, Manderscheid, Röglinger, & Rosemann, 2017	Human and processual dimensions/strategic aspects

diversity of R&D team composition suggests an important research direction.

2.2. Diversity of corporate research relationships

The characteristics of R&D capital can also reveal their effect on OI when the focus is on the research network at the related entrepreneurship or governance level (Ahn et al., 2017; Bogers et al., 2018). This aspect represents a distinct set of microfoundations combining human and corporate dimensions. Rasmussen and Clausen (2012) and West et al. (2014) investigate firms' OI based on entrepreneurship science and research-based background, particularly in enterprises characterised by extensive research activities. These scholars found that the breadth of founders' external relationships positively affects the identification and assimilation of external knowledge. The science-related background of entrepreneurs has been depicted as a distinct set of human capital conditions associated with the nature of internal R&D knowledge resources (Ahn et al., 2017; Bianchi et al., 2011; Soh & Subramanian, 2014). Moreover, the influence of science-connected entrepreneurs on open relationships is also seen as useful in supporting the establishment of the internal corporate network for research, mostly in the high-tech context (Soh & Subramanian, 2014). As a result, the characteristics and variety of science-related origins of entrepreneurial human capital and companies' membership in established research networks represent a research interest in the analysis of exploratory openness of biopharma.

2.3. Diversity of R&D resource allocation

Finally, recognising the connectedness of the interrelated conditions in OI practices (Bogers et al., 2017), we ask how the diversity of R&D resource allocations fits in the microfoundations aspects for exploratory openness. This aspect represents a distinct set of microfoundations, combining human and process dimensions. Recent studies engaging in the debate on openness have revealed that different external source practices must be aligned with an appropriate R&D strategy to ensure that OI can be successfully leveraged (Bogers et al., 2017). To support open search over time, organisations need to reconfigure their internal R&D resources, depending on how research and technology niches can be expanded. Hosseini et al. (2017) revealed that different OI strategies, in terms of search breadth and depth, can be supported by an appropriate strategy with respect to companies' vision and decisions to compete within different technology areas. This helps companies in spanning technological distances and exploring new technological areas. In this regard, strategic orientation in terms of R&D resource allocation can affect the effectiveness of OI (Bogers et al., 2017), and this effect is especially strong with a research entrepreneurial orientation (Cheng & Huizingh, 2014). Resultantly, the characteristics and variety of companies' portfolios of research areas represent an added condition to be considered in the analysis of exploratory OI of biopharma. In summary, looking at the microfoundations aspects, the three aspects of R&D diversity (i.e. team composition, corporate research relationships and resource allocation) combine the organisational, relational, and strategic dimensions discussed by Bogers et al. (2017) as an integrated set of drivers that form the basis of the effectiveness of firms' OI strategies.

3. Multi-method research

We based our research design on that suggested by Schneider and Rohlfing (2013), namely to use the set-theoretic multi-method research (MMR) approach to perform an fsQCA and a post-fsQCA process tracing procedure.

The fsQCA, based on Boolean algebra expressions (Ragin, 1988, 2008), is useful to compare cases according to a set of attributes (the conditions) to search for plausible causal relationships. The method performs well, even when the number of observations is not high (Fiss, 2011). Moreover, it enables the consideration of non-linear relations among the conditions (Meyer, Tsui, & Hinings, 1993), as well as the possibility of the same outcome from different initial conditions and different paths, that is, equifinality (Katz & Kahn, 1978).

Although there is no doubt about the strong link that exists between the fsQCA and cases (Ragin, 1988), there are still few studies that implement a dialogue between theory and cases (Fritzsche, 2014; Rihoux & Lobe, 2009). For this purpose, some recent works have confirmed the huge power of combining fsQCA with process tracing in the so-called comparative process tracing approach (Beach, 2018; Williams & Gemperle, 2017). The comparative process tracing approach is based on the identification and selection of cases that, according to the fsQCA results, are particularly useful to study and compare in order to bring causal mechanisms to light (Iannacci & Cornford, 2017; Seawright, 2005) by discerning model-related sources of deviance, and possibly to identify new relevant conditions (Williams & Gemperle, 2017). Some scholars have confirmed that process tracing requires a wide and complex variety of data about the cases to be analysed, from documentary sources to interviews (Beach, 2016; Tansey, 2007). Schneider and Rohlfing (2013) show a practical approach to comparative process tracing by fine-tuning an ad hoc procedure, which is our starting point for the analysis (Appendix A and B).

3.1. Data collection

To address our aim, data collection occurred in two phases: first, data were collected from a 12-item questionnaire (in Italian) and analysed by using fsQCA. Second, data on some sorted cases were gathered through unstructured interviews and secondary data, such as business reports, and analysed through process tracing analysis.

For the questionnaire, we selected a purposeful sample of biopharmaceutical firms listed as members of the Italian Association for the Development of Biotechnology (Assobiotec). Of the 104 pharmaceutical businesses across Italy that use biotechnology and are represented by Assobiotec, 79 firms were finally chosen based on their core business. We obtained email addresses of CEOs and research directors from Assobiotec and emailed the questionnaire with an

Table 2
Set characteristics.

		N.	Percentage (%)
Core business	Pure biotech	17	51,5%
	Pharmaceutical	3	9,1%
	Multinational multicore	10	30,3%
	Others	3	9,1%
Size	Micro	7	21,2
	Small1	13	39,4
	Medium	5	15,2
	Large	8	24,2

explanation of our study objective and an invitation for survey participation. We ran the survey for six months (September 2015–March 2016), with 33 biopharmaceutical firms responding (response rate 41%). Data were collected from one key informant per company. More than half the investigated firms were pure biotech (51.5%), about 30% were multinational and multi-core companies, and 60.6% were micro- and small-sized (see Table 2).

For the post-fsQCA analysis, additional information about selected companies were collected to highlight the causal mechanisms that lead to the phenomena emerging in the fsQCA results and questionnaire responses. Specifically, the relevant cases (Schneider & Rohlfing, 2013) were deepened by unstructured interviews with the top or middle managers in charge of R&D activities. Both authors conducted the interviews simultaneously, over a period of 3 months via Skype (30 min each) and by mail without following a predefined scheme. The interviews were aimed at understanding the typology and nature of the collaborations activated by the firms and their partners as well as the links among the microfoundations aspects at the basis of their collaborative orientation. Interviews were conducted in Italian, and data were recorded by handwritten notes. Secondary data from business reports obtained from Assobiotec and Internet sources completed the additional set of data (Beach, 2016).

3.2. Measures

In line with the theoretical framework, the breadth and depth of the firm knowledge base were translated into three different sources of diversity, which represent the three fsQCA conditions: R&D team composition, corporate research relationships, and R&D resource allocation. The outcome in the fsQCA analysis is exploratory openness. The detailed operationalisation of the constructs associated with the three conditions and the outcome is reported in Table 3.

3.2.1. Diversity of R&D team composition

The condition known as diversity in the educational background of the members of the R&D team (Bogers et al., 2018) encompasses the subject of study and the level of education. We calculated the reverse of the concentration indexes (Herfindahl–Hirschman index, HHI) of the percentage share of the subjects of study and the levels of education, respectively. Then the two results were averaged to obtain the measure of the diversity of the R&D team composition for each case.

3.2.2. Diversity of corporate research relationships

This condition depicts the breadth of the scientific networks at the related entrepreneurship and governance level by distinguishing between the connections from past research activities of founders and those arising from the scientific connections of the corporate group (Soh & Subramanian, 2014; West et al., 2014). Specifically, each dichotomous item (founder belonging, also in the past, to a personal scientific network; inclusion in the corporate group's scientific network) is equal to 1 if the connection were verified, and 0 otherwise. For each case, the overall condition measure is equal to 0 when the two items for the case are 0, equal to 1 when only one of the two is 1, and equal to 2 when both the first and second items are equal to 1.

3.2.3. Diversity of R&D resource allocation

The condition considers the diversification of the research areas and the diversity of the technological domains (Vanhaverbeke & Cloodt, 2014; Xia, 2013). The diversification of technological areas is quantified by comparing the number of therapeutic areas in which the firm operated to the total number of areas. The diversity degree of the technological knowledge domains of the firm is measured by comparing the number of pipeline phases in which it is active to the total number of phases. We obtain the overall measure of the condition by averaging the two items.

3.2.4. Exploratory OI (outcome)

We measure the level of exploratory OI by dividing the total number of active collaborations in the exploratory pipeline phases by the total number of the active collaborations that the firm developed in all phases. Basic research, drug discovery, and preclinical testing are considered as exploratory phases.

3.3. Data analysis

By using R software equipped with specific software packages (Dusa & Thiem, 2014; Quaranta & Schneider, 2013), we were able to perform fsQCA and test the existence and the effect of the interplay of the conditions upon the outcome. The original dataset from the questionnaire responses was calibrated by using the direct procedure. In this way, we turned it into a calibrated fuzzy set, consisting of any values ranging between 0 and 1.

The fsQCA resulted in testing the presence of necessary and sufficient conditions for the occurrence of the outcome. The necessity test was performed to understand whether there is a condition or a combination of conditions without which the outcome cannot occur. The sufficiency test revealed the conditions or combinations of conditions that can generate the outcome (Ragin, 2008). Cases were categorised as typical, irrelevant, or deviant, based on their fuzzy-set membership scores in the solution term (X), and the outcome (Y) (Appendix A). Some were particularly useful in analysis and comparison in the post-fsQCA phase to generate additional inferential value (Schneider & Rohlfing, 2013) (Appendix B).

The post-fsQCA analysis was used to identify and investigate the selected cases, by searching for causal mechanisms that can explain the solution path, and to search for alternative explanations of the outcome, in line with the principle of equifinality (Beach, 2018; Iannacci & Cornford, 2017). Qualitatively coded data from the interviews and from the complementary information sources were used in this phase. Post-fsQCA analysis of the typical cases (similar-outcome comparison) was useful for exploring the causal mechanisms binding the conditions included in the solution path and their role in generating the outcome. On the other hand, the investigation of the deviant cases for coverage and consistency (dissimilar-outcome comparisons) helped in understanding what if any circumstances, other than those already considered, were able 1) to generate the outcome or 2) to prevent the outcome even when the solution path was verified.

4. Qualitative comparative analysis

We calibrated the three conditions with reference to the qualitative anchors obtained from a cluster analysis. The anchors result from the 25th, 50th, and 75th percentiles (Table 4).

In the tests, we used 1) a consistency threshold of 0.9 for testing necessity (Legewie, 2013) and 2) a frequency threshold of 1 and a consistency threshold of 0.75 for testing sufficiency (Ragin, 2008). Based on the selected thresholds, no necessary condition or necessary combination of conditions appeared in the dataset (Table 5).

According to the thresholds chosen for the sufficiency test, a

Table 3
Operationalisation of constructs.

Construct	Measure	Categories	Construction and scale
R&D team composition	R&D employee's subject of study	10 subject categories: biotechnology, law, engineering, biology, economics, chemistry, pharmacy, physics, computer science, medicine and surgery.	Reverse of the HHI of the percentage share of each subject of study in the R&D team. 10 subject categories in total (0–10,000 scale: 0 = maximum concentration, 10,000 = maximum equidistribution)
	R&D employee's level of education	2 level categories: Graduate degree or less; Post graduate degree	Reverse of the HHI of the percentage share of each level of education in the R&D team. 2 level categories in total (0–10,000 scale: 0 = maximum concentration, 10,000 = maximum equidistribution)
Corporate research relationships	Research-related origin of the entrepreneur	Relationship: yes or no	Relationship with a scientific network due to past research activities of the entrepreneur (0 = no research origin, 1 = research origin)
	Membership in a corporate group	Membership: yes or no	Membership in an established corporate group's scientific network (0 = no corporate group; 1 = corporate group)
R&D resource allocation	Therapeutic areas	9 areas (EY, 2014): cardiovascular diseases and haematology; dermatology; gastrointestinal diseases; hepatic, endocrine, and metabolic diseases; infectious, inflammatory and autoimmune diseases; musculoskeletal diseases; neurology; oncology; respiratory diseases.	Statistical ratio comparing the number of therapeutic areas in which the firm is actively involved to the total number of areas considered. 9 areas in total (0–1 scale: 0 = no areas covered, 1 = all areas covered)
	Pipeline phases	5 phases: basic research, drug discovery, preclinical testing, clinical trials and registration	Statistical ratio comparing the number of pipeline phases in which the firm is actively involved to the total number of phases considered. 5 phases in total (0–1 scale: 0 = no phases covered, 1 = all phases covered)
Level of exploratory open innovation	Collaborations	Degree of exploratory openness	Number of exploratory collaborations for innovation/Total number of collaborations for innovation (0–1 scale). Basic research, drug discovery and preclinical testing are considered as exploratory phases

Table 4
Calibration rules and membership scores.

Construct	Calibration rule	Membership score
Exploratory openness	If < 0.01	0 (full non-membership)
	If =0.16	0.5 (cross-over point)
	If > 0.61	1 (full membership)
R&D team composition	If < 5933.00	0 (full non-membership)
	If =7699.77	0.5 (cross-over point)
	If > 9522.50	1 (full membership)
Corporate research relationships	If < 0.5	0 (full non-membership)
	If =1.5	0.5 (cross-over point)
	If > 2.0	1 (full membership)
R&D resource allocation	If < 0.100	0 (full non-membership)
	If =0.375	0.5 (cross-over point)
	If > 0.525	1 (full membership)

Table 5
Analysis of necessary conditions.

	Exploratory openness	
	Consistency	Coverage
R&D team composition	0.534	0.483
~ R&D team composition	0.649	0.605
Corporate research relationships	0.182	0.405
~ Corporate research relationships	0.331	0.762
R&D resource allocation	0.655	0.598
~ R&D resource allocation	0.512	0.481

~: negation of the condition (Schneider & Wagemann, 2012).

configurational analysis (Table 6) and a parsimonious solution for sufficiency emerged (Table 7).

The truth table confirms that the dataset is not particularly affected by limited diversity (Ragin, 2008), as only one of the possible combinations of conditions does not appear in the set. The sufficiency test reveals the presence of a parsimonious solution (Schneider & Wagemann, 2012) for the existence of the outcome. The sufficient condition consists of the simultaneous absence of diversity in R&D team composition and the presence of diversity in R&D resource allocation (see Table 7).

The fsQCA results were subjected to two types of robustness check, based on changing the calibration thresholds as well as the frequency and consistency thresholds (Skaaning, 2011). The original results were confirmed after the check. Specifically, after using the alternative calibration thresholds (Table 8), the necessity test confirmed that no necessary conditions emerge from the data, and the sufficiency test confirmed a parsimonious solution for all the alternative thresholds.

Moreover, the fsQCA was re-run twice after setting the frequency threshold equal to 2, once with the consistency threshold set at 0.65 and again at 0.77. The analysis appears to be robust because both the necessity test and the sufficiency test produced the same results (Skaaning, 2011).

5. Post-fuzzy set qualitative comparative analysis and case comparisons

For the post-fsQCA, the so-called enhanced XY plot is useful in visualising the fuzzy-set membership scores of the cases in terms of X (the fsQCA solution term) and Y (the outcome) (Schneider & Rohlfing, 2013) (Fig. 1).

After the application of the appropriate selection criteria (Appendix B), the following cases were selected for the comparisons:

- Similar-outcome comparison: typical case versus similar case (case 32 versus case 8);
- Dissimilar-outcome comparison number 1: typical case versus deviant case for consistency (case 32 versus case 21);
- Dissimilar-outcome comparison number 2: deviant case for coverage versus individually irrelevant case (IIR) (case 6 versus case 10).

The analysis of selected cases and their comparison allows us to understand the phenomenon under investigation. It enables us to be certain about which conditions caused the effects (chain of evidence) by providing a reasonable overview of the link between R&D resources and exploratory openness.

Table 6
Truth table and configurational analysis.

Exploratory openness	R&D team composition	Corporate research relationships	R&D resource allocation	Consistency	NCase	Case IDs
0	1	1	1	0.5037478	2	15,26
0	1	1	0	0.5702448	1	11
0	0	1	0	0.5310228	1	14
0	1	0	1	0.6394874	6	6,10,18,19,28,29
1	0	0	1	0.7759459	7	2,4,8,17,21,23,32
0	1	0	0	0.5464714	12	3,5,7,9,12,13,16,20,22,24,30,31
0	0	0	0	0.6294696	4	1,25,27,33

Table 7
Analysis of sufficient conditions.

Path	Conditions			Consistency	Coverage
	R&D team composition	Corporate research relationships	R&D resource allocation		
1	☒		□	0.745	0.696

☒: negation of the condition.
□: presence of the condition.

Table 8
Alternative calibration thresholds.

Construct	Full membership	Cross-over point	Non-membership
Exploratory openness	0.61	0.16	0.01
R&D team composition	9512.5	7689.77	5923
	9532.5	7609.77	5943
Corporate research relationships	1.9	1.4	0.4
	2.1	1.6	0.6
R&D resource allocation	0.520	0.370	0.095
	0.530	0.380	0.105

5.1. Similar-outcome comparison and dissimilar-outcome comparison number 1

The typical case (Company 32) is represented by an Italian academic spin-off founded in 2004 operating in different biological businesses. In the red segment of biotechnology research, the company is dedicated to research on the possible health benefits of organic micro-organisms. The company's basic research is aimed at the development of proprietary research protocol and compounds in the field of molecular biology and human cell cultures, and it is continuously exploring new uses of the knowledge of micro-organisms. Company development

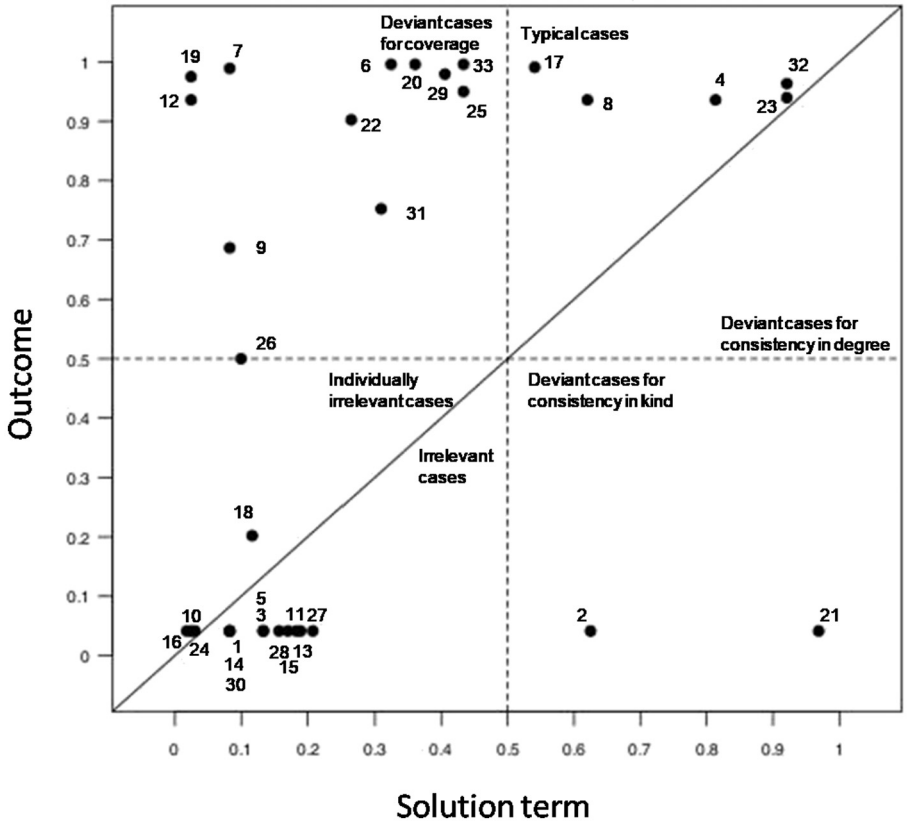

Fig. 1. Enhanced XY plot.

activity also concerns different therapeutic areas, including gastroenterology, gynaecology, and treatment of skin lesions and ulcers. In addition, its research centre specialised in biotechnology is actively engaged in the study and development of processes for transitioning the production of new organic active compounds to industrial scales. The R &D activity is an integral part of the Biotechnological Italian District, which houses both academic and government research centres as well as pharmaceutical and biotechnology firms. Many research partnerships have been focused on fuelling scientific discovery. Now, the company is expanding the mandate of this ecosystem at the international level to meet the needs of an evolving biopharma lifecycle, health care services, and increasingly complex rules systems.

> 'Internal research is just one way that biopharma companies expand their pipeline. We belong to a research network as it is the company's philosophy that we continually look to form partnerships. In today's increasingly specialised world, many new medicines reach patients because organisations recognise the importance of collaborating with other companies and research institutions. Earlier and more robust collaboration with key stakeholders is required to sustain returns on innovation often, not just for one product, but across multiple products in the same family'.
>
> (Source: Interview n.1, CEO)

The similar-outcome comparison shows a case of Company (8), which is a typical case. The company is a new research start-up founded in Italy in 2008. The company was created and developed by six researchers with the goal of exploring the use of vaccines for the treatment of various chronic diseases. Its current research is based on plasmid vaccination for some chronic autoimmune diseases and development of a new immunotherapeutic approach for the treatment of renal and prostate cancers. The company is also expanding research into autoimmune therapy in the fields of haematology and other diseases. Located within a technological park, the company has established an agreement with many universities and international research centres for access to both additional lab facilities and research fellows to fuel its integrated research chain by the complementary knowledge needs of its different projects.

> 'Our company is strengthening global reach through collaborations with local academic, governmental, and industrial companies. Scientific and business cooperation and contracting are pronounced, due to the massive research costs of biotechnology. The pharmaceuticals business is no longer viewed as a 'magic bullet' but as an element of systems of services and innovation for promoting health. This has been translated into new forms of innovation and models'.
>
> (Source: Interview n.3, CEO)

The deviant case for consistency is represented by Company 21, whose results are not open in the development of its research activity. There are similarities in the solution term between Company 21 and the typical case, and also some deviations, including the nature of the company's biopharma activity. Established initially as a specialised contract research organisation in Italy in 2008, the company has recently expanded its research service activity. It operates as a service research provider to both national and international pharmaceutical companies for the selection and promotion of active drug compounds to drug candidates in both preclinical and clinical development processes. Its research competences cover all therapeutic areas, with expertise in oncology. The company operates in isolation owing to the main characteristic of its activities, as it works through the tension between knowledge sharing and protection in R&D collaboration.

> 'With the knowledge characteristics at the core of our activities and with the huge relational dimension, we must combine better close and open relationships. First, there is the need to connect with the wealth of our internal knowledge, and at the same time, fill the know-how gap through traditional research and development, when required. Moreover, we are not able to protect our knowledge while scouting for research opportunities or further development'.
>
> (Source: Interview n.5, Research Manager)

5.2. Dissimilar-outcome comparison number 2

Company 6 (our selected deviant case for coverage) was founded in Italy in 1996 by an international four-member team and operates in red biotech. One founder is a researcher, but they decided to avoid incorporating the business as a university spin-off company. Company 6 steadily activates relationships with major global pharmaceutical companies to develop new risky products; moreover, it intensively cooperates with universities and other research entities. After its foundation, the need for new capital soon pushed the founders to turn to venture capitalists, who took over the majority share. This led the company to move its headquarters abroad to well-known technological park, while retaining some of its core research activities in Italy. These activities were very successful, and thus, the company reached important milestones in the market and filed several patents. A few years after its foundation, Company 6 launched an IPO and acquired other pharmaceutical companies.

> 'Mergers and acquisitions are an important tool for widening our business offer and for strengthening our commercial leadership all over Europe'.
>
> (Source: Interview n.6, Vice-President)

Company 10 (our IIR case) is the Italian division of a giant multinational company, a significant force in the global pharmaceutical industry, belonging to the world's 250 largest family businesses. In Italy, the group was established in 1972 as a family business, and within few years, it ranked among the top 20 pharmaceutical companies nationally. Thanks to its years-long experience in chemical discovery, Company 10 obtained important results which led to thousands of new molecules reaching the most advanced phases of the pipeline. Regarding the core business, Company 10 differs from Company 6 in that it is a multi-core business in the pharmaceutical, biotechnology, and biological industries. Compared to Company 6, Company 10 is much more diverse about R&D resource allocation, especially concerning the number of therapeutic areas in which it operates. The results show that Company 6 also differs from Company 10 regarding patent activity and being situated in a scientific park. Conversely, like company 6, company 10 has a high level of diversity in its R&D team composition, which is why the two firms are not members in the solution path.

6. Discussions

Our study uses the combination of fsQCA and process tracing for analysing the microfoundations of the exploratory OI in biopharma. The comparative process tracing approach is used to add inferential value to the analysis by going beyond the linear relationship between the solution term and the outcome. Our findings show that the biopharmaceutical firms included in our dataset, characterised by the simultaneous presence of the diversity in R&D resource allocation and absence of diversity in R&D team composition, are always open in the exploratory phases of their pipelines.

Three main contributions can be found in our work.

First, our analysis contributes to OI literature by addressing the recent topic of the microfoundations side of OI practices (Ahn et al., 2017; Bogers et al., 2018). By focusing on internal R&D resources and their links to exploratory openness, our findings contribute to the literature by assuming a multidimensional approach in this domain (Bogers et al., 2017). Our conceptual framework builds and improves on research on individual human diversity by Bogers et al. (2018) by exploring the diversity of R&D under organisational, corporate, and

strategic conditions. In line with the recent microfoundations view of Felin et al. (2015), we assume that several aspects of diversity of internal R&D resources need to be analysed when dependence on external sources of R&D increases. This study reveals that diversity in R&D resources contributes in a multifaceted way to firms' exploratory openness and is determined by the interactions among different dimensions of diversity. Our results suggest that firms that widen their R&D resource allocation to different research areas and processes have an advantage in exploratory openness. They can leverage this diversity in their open search strategy and might not have to create such diversity in R&D team composition (Bogers et al., 2018). Instead, no direct association has been found concerning the diversity of firms' research relationships, both in terms of belonging to an established corporate group or to a personal scientific network. As such, our theory contributes to further explore the role of multiple conditions of the diversity of R&D resources, which may represent a prerequisite for the relationship between the microfoundations of exploratory openness and R&D resources.

Second, we complement existing research on biopharma OI, which in current studies has a more general setting by focusing on OI practices on the whole (Bianchi et al., 2011; Schuhmacher et al., 2018; Xia, 2013; Xia & Roper, 2016) or are restricted to the organisational boundary of R&D investment (Chiaroni, Chiesa, & Frattini, 2009; Salter et al., 2015). Our analysis confirms that the diversity of R&D resources emerges at the microfoundations as a specific strategic aspect of research strategy when the focus is on exploratory openness. The biopharma research strategy is moving toward a more cooperative-competitive research model (Xia & Roper, 2016), and such highly research-focused firms, owing to the fact they operate in different pipeline phases and therapeutic areas, can open their research processes to search for various and versatile additional R&D resources. Not completely in line with previous research on the role of human capital in a firm's open strategy (Ahn et al., 2017; Bogers et al., 2018), this study demonstrates that the exploratory openness in biopharma is influenced by the diversity of R&D resources allocation. A diversified research basis, involving different scientific and technology domains, leads firms to be more open and establish new and fruitful linkages with external partners to augment the diversity of their knowledge endowment. In the context of exploratory practices, involving highly qualitative and research-based knowledge, companies that expand their knowledge breadth, by extending it to different technological and research areas, favour the accumulation of differentiated knowledge on which to build further partnerships with external actors. Moreover, the diversity of R&D resource allocation opens an alternative perspective which shows a positive relationship between a firm's knowledge breadth and its ability to manage new technological paths in-house (Lo Nigro et al., 2014). The absence of diversity in R&D team composition seems to overcome the need to invest in more or less specialised human capital, as their research strategy leads them to search for such specialised knowledge through external partners.

Third, by implementing the MMR approach, the study provides an insightful way to explore the underlying links connected to the microfoundations of exploratory openness. Specifically, the similar-outcome and dissimilar-outcome comparisons reveal the presence of additional elements relevant to the proposed framework. This aspect represents an advantage that adds rigour to the analysis by validating and enriching the framework (Schneider & Rohlfing, 2013). Specifically, exploratory openness is the way to proceed for innovation in firms founded as research firms, thereby realizing the huge potential of the OI framework in the exploratory section of their pipeline. In line with some studies (Huang & Rice, 2013), being located in scientific and technological parks can be assumed as allowing some influence on the exploratory openness in high-tech industries. The opportunity for co-location, seen as a potential for taking part in the broader context of knowledge exchange, would induce biopharmaceutical firms to open their exploratory innovation processes because it could be easier for such companies to have access to the broader domain-specific repertoire, to search in areas they are unfamiliar with, and to combine the diversity of internal and external knowledge bases. In line with some studies in the field (Toma, Secundo, & Passiante, 2018), this aspect also matches the presence of other conditions for biopharmaceutical exploratory openness like intellectual property value and protection. These conditions could be an additional microfoundations aspect of the knowledge creation mechanism, which could support investment in different knowledge areas and thereby increase R&D knowledge diversity.

7. Theoretical implications

As empirically shown and previously discussed, this study has some relevant theoretical implications. In line with some current studies on OI and their findings, this study suggests that firms struggling with open search requirements seek more focus on the microfoundations aspects of internal knowledge mechanisms (Ahn et al., 2017; Bogers et al., 2018). The OI debate has started to focus on the nature of R&D resources at the individual level (Bogers et al., 2018), demonstrating that the OI framework relies on the diversity of individual knowledge and previous learning competencies. From a theoretical perspective, our work provides evidence that the links between R&D resources and the degree of a firm's openness involve more strategic and processual dimensions when the focus is on intensive knowledge open activities. This result partially confirms the previous research on the topic. Future studies should further investigate the role of the creation of a base of diverse and rich company knowledge through internal research activities in the development of OI capability in a high research-based context. The diversity of R&D research activities as a form of knowledge breadth can also explain the propensity of the company to engage with and explore more innovative research paths to access missing complementary knowledge. In such a view, the breadth and depth of R&D resources could match Laursen and Salter's (2006) analysis focused on external relations to better address the effectiveness of an open strategy. There is still much theoretical and empirical research potential to be explored concerning the antecedents of OI practices (Bogers et al., 2018; Felin et al., 2015). Further studies can help to better understand how microfoundations aspects combine with the characteristics of external partners to improve the effectiveness of OI strategies.

Some OI studies recognise the commonalities between internal and external knowledge resources as an essential condition for firms to access and exploit external superior knowledge (Xia & Roper, 2016). As this study reveals, at the microfoundations level, the impact of diversity in firm R&D resources on open search strategies can also bear on how external knowledge can be used and innovation performance can be improved. Dealing with external knowledge seems to give rise to more questions on how the nature and breadth of internal knowledge need to be improved and developed (Vanhaverbeke & Cloodt, 2014; Xia & Roper, 2016).

8. Managerial implications

Our work has managerial implications, too. First, our findings make it possible to provide a wider perspective on the strategic decisions of top managers and entrepreneurs, which are aimed at diversifying or expanding business activities to more research areas and pipeline phases. These decisions, in fact, prove to be determinants of not only dimensional growth and business development but also the innovative process because they contribute to activating exploratory OI mechanisms. This combination is particularly interesting in the case of biopharma, which is a highly innovative and competitive industry. Companies can therefore seize the synergies triggered by choices to strengthen the business and reduce risks with continuous innovative drives.

Furthermore, our results show the interconnection between strategic and open decisions, bringing to light the role of different

conditions related to research strategy. Managers must take seriously their choices regarding different conditions to nurture the diversity of R &D resources, which can have a complementary effect on the overall propensity for exploratory openness.

Finally, our results have useful implications for policymakers. The links between incentives and R&D resources seem to be consistent with OI goals. Our findings affirm the essential role of the strategic dynamism of these companies in the exploratory OI process; therefore, the presence of entrepreneurial and managerial attitudes aimed at diversifying the business or expanding in several pipeline phases appears to deserve more attention from policymakers.

9. Limitations and further research

Our work includes some limitations that should be addressed in futures research. The first limitation relates to the characteristics of the chosen businesses. Biopharma, even though it is of interest on an empirical basis, has several unique characteristics which can limit or facilitate specific aspects of open source innovation. Therefore, future studies could explore other high-tech industries to analyse the microfoundations of exploratory openness.

Second, it could be of interest to extend the analysis by considering additional dimensions of diversity. As the chosen method suggests, it could be useful in further research to return to the field and gather a significant body of qualitative information to be able to consider additional conditions that are potentially interesting for enriching the conceptual framework.

Third, the analysis is limited by the method selected. Future research could test the conceptual framework by alternatively combining qualitative and quantitative methods. Doing so would help overcome the limitations due to the small sample size and the use of non-probability sampling and make it possible to generalise the conclusions to the larger population.

Finally, examining observations of the selected cases over time could help to detect and analyse the temporal pathways associated with the openness of biopharmaceutical companies (Iannacci & Cornford, 2017). In this sense, it could be possible to reveal the effects of specific changes in the dynamic context and management of these enterprises.

Declaration of interest

None.

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Appendix A

Type of cases in post-fsQCA analysis of sufficient conditions

Case	Definition
Typical	It shows both the X and Y (both membership scores are higher than 0.5), and its membership in the X is lower than the membership in the Y
Deviant for coverage	The case is consistent with the statement of sufficiency. However, it is member of the outcome (its membership in the Y is higher than 0.5) and not member of the term
Deviant for consistency in kind	The case is member of the solution term, but it is not member of the outcome, that is the membership in the X is higher than 0.5 and the membership in the Y is lower than 0.5
Deviant for consistency in degree	The membership in the X and in the Y is higher than 0.5 (as the typical case), but the membership in the X is higher than the membership in the Y
Individually irrelevant (IIR)	The case is not member of the solution path and the outcome. The membership in the X is lower than the membership in the Y
Irrelevant	The case is not member of the solution path and the outcome. The membership in the X is higher than the membership in the Y

Source: authors on Schneider and Rohlfing (2013).

Appendix B

Case selection criteria

Analysis	Case type	Selection criteria
Single case	Typical	The most typical case is the closest to the upper-right corner of the XY plot
	Deviant for coverage	The selected deviant case for coverage is the closest one to the membership of 1 in the outcome and in its truth table row
Comparative	Similar outcome	The most typical case is compared to the second typical one, located into the lower left side of the typical cases section in the XY plot
	Dissimilar outcome 1	The typical case is compared to the deviant case for consistency that has the maximum membership in the solution term and the maximum difference in its membership in the outcome
	Dissimilar outcome 2	The selected deviant case for coverage is compared to the IIR that belongs to its truth table row, and having similar membership in the row and maximum difference in its membership the outcome

Source: authors on Schneider and Rohlfing (2013).

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