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Effects of ambidextrous and specialized R&D strategies on firm performance: The contingent role of industry orientation

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A B S T R A C T

Innovative firms must decide whether they should *specialize* in either exploratory or exploitative R&D or adopt an *ambidextrous* R&D-strategy (pursue both). This study extends research on exploration/exploitation by explaining how the effects of ambidextrous and specialized R&D-strategies on a focal firm's performance are influenced by the R&D-strategies adopted by other firms in its industry. Comparing a firm's R&D-strategy with those of its intra-industry peers enables us to identify how the performance-enhancing advantages of ambidextrous and specialized R&D-strategies change across industries and which R&D-strategy is optimal for the firm. Our framework and longitudinal analysis of 32,526 observations indicate that an R&D-strategy that is similar to that of the rest of the industry decreases firm performance, whereas an R&D-strategy that differs from the industry's dominant R&D-strategy enhances performance. The study also explains the mechanisms through which certain industry environments reduce the need to be ambidextrous and help specialized firms enhance their performance.

1. Introduction

Although both exploratory and exploitative activities can potentially be advantageous for firm performance, they involve considerable trade-offs and require different knowledge and firm capabilities (Bhandari et al., 2020; March 1991). Hence, firms that seek to achieve superior performance must decide whether they should invest a similar amount of resources in both activities (i.e., choose an *ambidextrous strategy*) or invest most of their resources in either exploration *or* exploitation (i.e., adopt a *specialized strategy*). While the role of ambidexterity has attracted considerable attention (Solís-Molina et al., 2018), prior empirical findings are mixed. They indicate that an ambidextrous strategy is not always advantageous (Felício et al., 2019; Lu Jin et al., 2016), suggesting that its effects on firm performance can be positive (Cao et al., 2009; Morgan & Berthon, 2008), negative (Rothaermel & Alexandre, 2009) or insignificant (Bierly & Daly, 2007).

Although prior research has recognized that the benefits of ambidexterity may vary in different environments and conditions (Auh & Menguc, 2005; Uotila et al., 2009), we have a rather limited understanding of how the effects of ambidextrous and specialized strategies on firm performance are influenced by the corresponding strategies that other firms in an industry adopt. This is an important omission given that prior research emphasizes the value of examining a focal firm's strategy within the context of and vis-à-vis the strategies of its peers (Chen & Miller, 2012). This view suggests that a firm's performance is not merely determined by its own strategy, but also by the strategy pursued by its competitors and collaborators. Hence, to avoid incorrect conclusions, we must understand how specific *combinations* between a firm's own strategy and that of its intra-industry peers affect performance.

The current study addresses the above limitation in the context of innovative firms that conduct research and development (R&D). It develops a framework that identifies each focal firm's R&D strategy (ambidextrous or specialized) and compares how it differs from (or whether it is similar with) the R&D strategy that the majority of other firms within its industry adopt. In this study, we develop the term *industry R&D orientation* to refer to each industry's dominant R&D strategy. Such comparison is particularly important because the strategies of other firms determine whether these firms are potential competitors or collaborators, and in turn whether their activities substitute or complement the expertise, knowledge, and capabilities of the focal firm.

Capturing differences and similarities in the R&D strategy of each firm and that of its peers allows us to address three key questions: **(1)** how do the R&D strategies adopted by intra-industry peers determine

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whether the focal firm should be ambidextrous or specialize? **(2)** when a firm makes the strategic decision to specialize, which specialized R&D strategy (exploratory or exploitative) and in which industries is more advantageous for firm performance? and **(3)** how are the effects of ambidextrous and specialized R&D strategies on firm performance influenced by an industry's R&D orientation? To address these questions, we integrate insights from organization learning theory (Huber, 1991; Levitt & March 1988) and industrial organization economics (Bain, 1968; McGahan & Porter, 1997; Jacobides et al., 2006). We develop and test a framework using longitudinal data on firms' exploratory and exploitative R&D investments for a 10-year period (32,526 observations). These data allow us to capture whether firms engage simultaneously in both R&D activities or specialize in one activity.

The study makes three contributions. First, it explains why the effects of exploration and exploitation on firm performance differ across industries and demonstrates in what ways they differ. Prior studies examine how the effects of exploration/exploitation are influenced by firm-specific idiosyncrasies (Cao et al., 2009; Wenke et al., 2021) and market conditions (Auh & Menguc, 2005; Osiyevskyy et al., 2020). Our framework extends these studies and the exploration/exploitation literature by showing how the performance effects of exploratory/exploitative R&D are affected by the R&D strategies adopted by the firm's potential competitors and collaborators. Specifically, it shows that a firm's R&D strategy enhances its performance when it differs from the R&D strategy adopted by most intra-industry firms, but (in contrast) it reduces firm performance when it is similar with the R&D strategy that is widely adopted by the industry. Hence, a firm that specializes in exploitative R&D benefits from that strategy when most firms in its industry specialize in exploratory R&D (i.e., in the opposite strategy). However, the same strategy becomes less beneficial when most other firms specialize in exploitative R&D. Our study therefore enhances understanding of why each R&D strategy might be beneficial in some industries, but not in others.

Second, the proposed framework contributes to research on exploration and exploitation (Solís-Molina et al., 2018; Bhandari et al., 2020) by identifying and testing two industry-specific mechanisms through which R&D strategies affect firm performance. Specifically, the study shows that similarities and differences in the R&D strategy of the focal firm and those of its intra-industry peers change the competitive advantages that ambidextrous and specialized R&D strategies offer to the focal firm by affecting two key mechanisms: the *availability* of external expertise and opportunities in the industry, and how *useful and effective* such opportunities are in increasing firm performance. Third, while the literature has typically emphasized the role of ambidexterity in achieving superior performance (March 1991; He & Wong, 2004), the above two mechanisms explain why firms that are not ambidextrous can still succeed in improving their performance. Challenging the view that ambidexterity is always advantageous, we show that whilst some firms remain specialized for long time periods, they operate in industries that allow them to access and utilize external opportunities and expertise more effectively, enhancing their performance without the need to be ambidextrous (Gupta et al., 2006).

2. Theoretical background

Prior research has focused on two distinct, albeit complementary explanations about the determinants of firm performance: an *organizational learning* perspective and an *industry-based* perspective. These perspectives rely on organizational learning theory and industrial organization economics, respectively. The following sections discuss the underlying premises of each perspective and explain why we have chosen to combine them in our framework.

2.1. Organizational learning perspectives

This perspective hinges on the premise that performance differs across firms due to variations in their learning (Huber, 1991). Specifically, it focuses on the view that firms engage in different exploratory and/or exploitative innovative activities (including R&D) that influence firms' knowledge and learning (Levinthal & March 1993; Levitt & March 1988), create different advantages and costs, and in turn lead to different performance outcomes (D'Este et al., 2018; Kafouros et al., 2022; Swift, 2016). The underlying logic of this explanation therefore lies in how exploitative and exploratory activities differ.

Exploitative activities (including exploitative R&D) require firms to leverage existing knowledge, improve efficiency, and refine their technologies and product offerings (Schilling et al., 2003; Koryak et al., 2018). Firms improve performance by strengthening their existing competencies, extending products' life cycle, and creating economies of scale and scope (Auh & Menguc, 2005; Baum et al., 2000). As such, exploitative activities are less risky and have predictable returns (Abernathy & Clark, 1985). *Exploratory activities* (including exploratory R&D) require firms to engage in experimentation, search for distant knowledge, and create new ideas and technologies that can potentially improve firm performance by generating new revenue streams (Morgan & Berthon, 2008). They can also help firms identify opportunities (Rothaermel & Alexandre, 2009) and combine knowledge from different domains that may result in new markets (He & Wong, 2004).

In sum, the success of exploitative R&D depends on the refinement, efficiency and repetitive execution (i.e., adaptive learning), whereas the success of exploratory R&D is driven by risk taking and experimentation (i.e., generative learning) (March 1991). Accordingly, this perspective postulates that inter-firm differences in performance are driven by variations in exploratory or exploitative activities and by the different (and often incompatible) learning requirements of each activity (Lavie et al., 2011).

2.2. Industry-based perspectives

This perspective is based on theory from industrial organization economics. It postulates that firm performance is affected by the structure and characteristics of the industries in which firms operate (Bain, 1968; McGahan & Porter, 1997; Rumelt, 1991). Accordingly, this view suggests that the industry's structure and characteristics determine how advantageous and effective a firm's chosen strategy is (Wernerfelt & Montgomery, 1988), which can in turn have a profound effect on its performance (McGahan & Porter, 1997). This perspective is characterized by two key premises that are relevant and useful to our analysis.

First, it conceptualizes firms as 'input combiners' – i.e., firms are seen as entities that seek to enhance their performance by identifying and combining various external inputs and resources (Conner, 1991), including knowledge (Kafouros et al., 2018). To do so, firms try to drive some competitors out of the market while colluding and collaborating with other firms. Hence, a firm's industry plays a crucial role because not only it determines the availability and effectiveness of external markets, but also influences various opportunities (e.g., for collaboration and knowledge sourcing) that affect a firm's ability to access inputs, complement its own activities (including R&D) and implement its strategy.

Second, each industry's structure and characteristics provide certain contours that influence how firms interact (Jacobides et al., 2006) and how they develop their goals and strategies (Conner, 1991). Some firms in each industry end up having similar goals, follow common paths and research strategies, invest in similar technologies, and are bound by similar commitments (DeSarbo & Grewal, 2008). By contrast, other firms adopt strategies that differ considerably from the strategies adopted by their intra-industry peers. Such similarities and differences in firm strategies in each industry are seen as central within this perspective because they determine the *strategic fit* between the firm's offerings and the industry's needs and, thereby, the value and effectiveness of the firm's chosen strategy.

2.3. The need for an integrative approach

We combine organizational learning and industry-based perspectives for two reasons. First, while the two perspectives have been fruitful in explaining performance outcomes, each perspective provides only a partial account of firm performance given that the organizational learning perspective focuses on idiosyncratic firm attributes and learning, while the industry-based perspective considers environmental characteristics. Hence, although both perspectives explain firm performance, their assumptions and boundary conditions differ. In this respect, the two perspectives complement one another.

Second, combining the two perspectives is helpful because they are interdependent. Although exploratory and/or exploitative activities have the potential to enhance performance (March 1991), this potential may not be realized in industries in which competitors focus on similar goals and activities. Similarly, while the industry-based perspective often assumes that all firms in an industry are competitors, firms with certain exploratory or exploitative expertise might be affected differently by competition. Hence, as industry dynamics influence (and are influenced) by organizational learning aspects, combining the two perspectives can explain firm performance more effectively and may help us understand why the advantages of a given R&D strategy vary considerably in different industries.

3. Conceptual framework

Although firms must decide whether they should adopt an *ambidextrous R&D strategy* or focus on one of the two activities only (i.e., *specialize*), it is unclear how the effects of such R&D strategies on firm performance are influenced by the strategy adopted by other firms within the industry. This section develops a conceptual framework to address this question.

3.1. Ambidexterity vs Specialization: Two different strategic approaches

Regarding ambidexterity, organizational learning perspectives (Levitt & March 1988; Huber, 1991) suggest that although exploratory and exploitative activities may complement one another in enhancing firm performance, they require different capabilities, knowledge (Lavie et al., 2011) and organizational structures (Raisch et al., 2018). Hence, firms need specific capabilities to alternate between the two activities (Lubatkin et al., 2006). Nevertheless, some studies suggest that ambidexterity can help firms improve their performance (He & Wong, 2004) and, accordingly, recommend that firms should engage in both activities (O'Reilly & Tushman, 2013).

The logic behind this suggestion is rooted in the organizational learning perspective (March 1991). It suggests that if a firm engages in exploitative activities only, existing ideas and technologies will gradually become obsolete, and revenues will decline. Equally, if a firm engages in explorative activities only, its new ideas and technologies will remain underutilized and will not generate sufficient revenues (Tushman & O'Reilly, 1996). The organizational learning literature has examined the performance effects of ambidexterity (O'Reilly & Tushman, 2013; Bierly & Daly, 2007) but the empirical findings are mixed, not always supporting the view that ambidexterity is beneficial for all firms (Ebben & Johnson, 2005) and in all industries (Uotila et al., 2009). Hence, certain factors, including absorptive capacity (Rothaermel & Alexandre, 2009), environmental munificence (Cao et al., 2009) and firm resources (Bhandari et al., 2020) may influence the usefulness of ambidexterity (Solís-Molina et al., 2018).

The second strategic approach that firms may choose is that of *specialization*. Although specialization as a concept is well recognized in industrial organization economics, the effects of specialization on firm performance have attracted less attention in the exploration/exploitation literature. This is surprizing as many firms are not ambidextrous and instead choose to specialize (focus almost exclusively on one of the two activities). Specialization requires firms to limit the scope of their activities and invest most of their resources, time, and effort in either exploratory or exploitative activities (rather than both). Specialization provides two performance-enhancing advantages (Stettner & Lavie, 2014; Solís-Molina et al., 2018). First, it increases the efficiency with which firms perform the chosen exploratory or exploitative activities due to repetition in the execution of tasks and the accumulation of experience (Hanks & Chandler, 1994), knowledge and expertise in these areas (Baum et al., 2000). Second, specialization enables firms to perform (exploratory *or* exploitative) activities at a lower marginal cost, enhancing firm efficiency (Piao & Zajac, 2016) and performance (Swift, 2016). Lower marginal costs and higher returns result from improving the execution of these activities as firms learn faster and more effectively in areas of established expertise than in areas in which they are not specialized (Hanks & Chandler, 1994; Baum et al., 2000).

In summary, while prior theory suggests that both strategies can be beneficial, the empirical literature has not established a consensus (O'Reilly & Tushman, 2013), showing that the effects of ambidexterity on firm performance can be positive (Cao et al., 2009; Morgan & Berthon, 2008), insignificant (Bierly & Daly, 2007), negative (Rothaermel & Alexandre, 2009) or less important when competition intensifies (Auh & Menguc, 2005).

3.2. Conceptual framework: R&D strategy and industry R&D orientation

To improve theoretical explanations about firm performance, our framework suggests that we must examine not only the R&D strategy (ambidextrous or specialized) of the focal firm, but also the corresponding R&D strategies of its industry peers. This view is highly consistent with the industry-based perspective that underscores the value of examining the actions of a firm's peers, including competitors and collaborators (Bain, 1968; Chen & Miller, 2012; Rumelt, 1991). A key prediction of our framework is that specific firm-industry combinations determine how beneficial ambidextrous and specialized R&D strategies are for firm performance. To understand these effects, we must first recognize that some firms share similar strategic goals and focus on a strategy that is similar with that of other firms in their industry. In such cases, firms invest in similar exploration and/or exploitation activities and are bound by similar commitments (DeSarbo & Grewal, 2008). By contrast, other firms pursue strategies that differ from those of their intra-industry peers. In such situations, firms invest in dissimilar activities and their commitments are considerably different.

Building on the above theoretical insights, we develop the notion of *industry R&D orientation* to capture the exploratory and exploitative R&D activities of firms in each industry. We argue that each industry's orientation depends on the extent to which most firms within the industry 1) specialize in exploratory R&D, 2) specialize in exploitative R&D, or 3) invest in both (i.e., they are ambidextrous). Accordingly, we classify industries as exploitative-oriented, exploratory-oriented, or ambidextrous. Hence:

- *Exploitative-oriented industries* are characterized by many firms that specialize in exploitative R&D, whereas only few firms specialize in exploratory R&D.
- *Exploratory-oriented industries* exhibit the opposite pattern (i.e., most firms specialize in exploratory R&D).
- *Ambidextrous industries* exhibit a similar number of firms that specialize in exploratory or exploitative R&D, or they are ambidextrous and make a similar investment in both. Ambidextrous industries therefore feature a similar availability of exploration-specific and exploitation-specific R&D opportunities.

We argue that understanding the strategy adopted by most firms in each industry is important because it determines how effective a focal firm's own R&D strategy is in enhancing its performance. Table 1 summarizes our framework. The vertical axis reflects the focal firm's

Table 1
Conceptual framework: Focal firm's R&D strategy and industry R&D orientation.

R&D Strategy of the focal firm	R&D Strategy of the majority of industry peers (industry R&D orientation): ***Exploitative*-oriented**	***Ambidextrous***	***Exploratory*-oriented**
*The focal firm specializes in **exploitative R&D***	Cell 1 (-)	**Cell 2 (+)**	**Cell 3 (+)**
*The focal firm is **ambidextrous***	Cell 4 (-)	**Cell 5 (+)**	Cell 6 (-)
*The focal firm specializes in **exploratory R&D***	**Cell 7 (+)**	**Cell 8 (+)**	Cell 9 (-)

strategy, while the horizontal axis reflects the strategy adopted by most of its industry peers. As such, there are nine possible combinations (cells) that reflect the strategy that the focal firm adopts vis-à-vis the strategy adopted by most firms in its industry. As Table 1 indicates, these different combinations are as follows: **(1)** the focal firm chooses to specialize in exploratory or exploitative R&D and its chosen strategy is *similar* to that of the majority of its industry peers (i.e., cells 1 and 9), **(2)** the focal firm chooses to specialize in exploratory or exploitative R&D and its chosen strategy *differs* from that of the majority of its industry peers (i.e., cells 2, 3, 7 and 8), **(3)** the focal firm is ambidextrous and operates in an ambidextrous industry (i.e., cell 5), **(4)** the focal firm is ambidextrous while the majority of its industry peers specialize in either exploratory or exploitative R&D (i.e., cells 4 and 6).

Building on the conceptual framework presented in Table 1, the overarching premise of our analysis is that although both specialization and ambidexterity have certain advantages, their effects on firm performance depend on the exploratory and exploitative R&D strategy adopted by other firms in the industry. We argue that the strategies of industry peers change the impact that the focal firm's own strategy has on its performance through two mechanisms.

Regarding the first mechanism, building on the industry-based perspective (Bain, 1968; McGahan & Porter, 1997), we argue that the strategy of industry peers affects considerably the *availability* of external opportunities and therefore the *difficulty* for the focal firm to identify external R&D opportunities that facilitate valuable collaborative agreements as well as provide access to potentially complementary knowledge, skills and expertise that they do not themselves possess (Wassmer et al., 2017). The focal firm can access external knowledge through **a)** collaborative agreements and/or **b)** knowledge leakage and imitation. Specifically, it can engage in (formal) external R&D collaborative agreements to purchase R&D services or acquire patented inventions and/or non-patented technologies from domestic and foreign organizations. It can also access external knowledge by engaging in imitation (Ali, 2021; Kafouros et al., 2021) and by exploiting knowledge spillovers that can enrich the firm's own knowledge (Kafouros et al., 2018). This reasoning is consistent with organizational learning perspectives that suggest that exploratory and exploitative learning affects the firm's innovation and imitation strategies and thereby its competitive advantages.

Regarding the second mechanism, the strategy that industry peers adopt also influences the *effectiveness* of the above external opportunities and advantages in enhancing the performance of the focal firm – i.e., they change how valuable and useful external opportunities are to the focal firm (rather than the availability of opportunities that was discussed in the first mechanism). When the focal firm operates in an industry in which most other firms engage in a similar strategy, the potential overlap of such activities decreases their value and usefulness. Hence, such value and usefulness will not be as significant as it can be in industries in which external opportunities differ from what the focal firm focuses on.

4. Hypotheses

Using the mechanisms discussed earlier, we develop hypotheses for the combinations (cells) depicted in Table 1. We combine the organizational learning perspective that emphasizes that diverse knowledge can complement the firm's own knowledge (Levitt & March 1988; Huber, 1991) and the industry-based perspective that highlights that external opportunities are determined by the strategy of industry peers (Chen & Miller, 2012). Accordingly, our framework predicts that the focal firm has fewer and less effective opportunities in cells 1, 4, 6 and 9. In such situations, the firm's competitive advantages and performance are affected negatively. By contrast, the availability and effectiveness of such opportunities are higher in cells 2, 3, 5, 7 and 8 (highlighted in bold) given that the firm's expertise differs from that of its peers. In such cases, the firm's competitive advantages and performance are strengthened.

4.1. The strategy of the focal firm is similar to that of its intra-industry peers (cells 1 & 9)

We expect specialization in exploitative R&D to have a negative effect on the performance of the focal firm when most firms within its industry also specialize in exploitative R&D (i.e., cell 1). First, the focal firm in such situations is more likely to be exposed to knowledge, expertise and capabilities that are similar to its own (Levinthal & March 1993; Leonard-Barton, 1992). According to the first mechanism discussed earlier (and consistent with organizational learning theory), the greater the similarity in the capabilities and knowledge of firms in each industry is, the lower the number of opportunities for knowledge sourcing and recombination will be (Fleming, 2001; Katila & Ahuja, 2002). Therefore, identifying external expertise, capabilities and knowledge becomes more difficult (Wu & Shanley, 2009), decreasing the focal firm's ability to use the market to benefit from its exploitative R&D activities.

The industry-based perspective also postulates that firm performance is determined by the structural characteristics of industries (Jacobides et al., 2006). Specifically, prior research shows that when firms within an industry are homogenous, they tend to invest in similar technologies, perform similar functions and serve the same customer base (Gulati et al., 2000). The limited number of firms that specialize in exploratory R&D prevents firms that specialize in exploitative R&D from identifying useful and complementary expertise and capabilities. It also increases the difficulty of establishing exploratory-specific collaborative agreements that could enhance the returns to their expertise in exploitative R&D. The focal firm may instead partner with firms that possess similar capabilities, which may result in less productive relationships (Gulati et al., 2000). Hence, the limited availability of opportunities in exploitative-oriented industries decreases the likelihood of engaging in external R&D that can offer collaborative and knowledge-sourcing advantages to complement the firm's activities.

Furthermore, firms cannot find new ideas at the rate they need in industries in which the level of exploitative activity is high and explorative activity is limited. Hence, as the organizational learning perspective suggests, they end up overutilizing prior ideas (Uotila et al., 2009). Such industries make it *difficult* for firms that specialize in exploitative R&D to collaborate with or source new ideas (Williamson, 1981) from firms that specialize in exploratory R&D (given that there are only few firms that specialize in exploratory R&D). Furthermore, the terms of these collaborative and knowledge sourcing agreements are likely to be less beneficial for the focal firm that specializes in exploitative R&D because the bargaining power of the few exploratory-oriented firms in the market is higher.

Second, according to the industry-based perspective, superior performance is driven by the focal firm's ability to achieve differentiation (Bain, 1968; Conner, 1991). The abundance of exploitative expertise and capabilities in these industries makes the offerings and outputs of a focal firm that specializes in exploitative R&D less rare and easier to be substituted by the knowledge and capabilities of other firms within the industry (Levinthal & March 1993; Kyriakopoulos & Moorman, 2004). They therefore offer weaker competitive advantages to the focal firm and their impact on firm performance is limited (Cassiman & Veugelers, 2006; Vassolo et al., 2004). In line with this reasoning, prior research shows that the value of technological investments declines when firms make similar investments or focus on similar offerings (Vassolo et al., 2004; Belderbos & Zou, 2009).

Although not all exploitative-oriented firms focus on the same technologies, they often rely on a similar knowledge base to refine existing products and technologies, and respond to market developments (Dierickx & Cool, 1989). However, the usefulness and potential value of exploitative outputs may be limited because they often compete with many other exploitative outputs offered by competitors. This logic is in line with the industry-based view, suggesting that firms in such situations have few opportunities to become effective 'input combiners' (Bain, 1968). Their capabilities and outputs therefore are more likely to be substituted by those in the industry (Auh & Menguc, 2005). This in turn decreases the advantages of specializing in exploitative R&D, leading to diminishing returns in exploitative-oriented industries. Hence:

H1a (cell 1): Specializing in exploitative R&D has a negative effect on the performance of the focal firm when it operates in an exploitative-oriented industry.

The aforementioned mechanisms also apply to cases in which the focal firm specializes in exploratory R&D and operates in an exploratory-oriented industry (i.e., when the strategy of the focal firm is again similar to that of its peers). The industry-based perspective suggests that firms are less likely to collaborate when they have similar expertise. Similarly, the organizational learning perspective suggests that collaboration is less useful in such cases. Accordingly, we expect the *effectiveness* of collaborative and knowledge-sourcing opportunities in enhancing firm performance in such situations to be low, while the *difficulty* of identifying and engaging in such opportunities to be high. Due to creative destruction in exploratory industries (Abernathy & Clark, 1985), new technologies are replaced quickly with new ones (Uotila et al., 2009). The focal firm has fewer opportunities to use the market to get its ideas exploited as many of these ideas become obsolete quickly (Sørensen & Stuart, 2000). Therefore, the likelihood of accessing exploitative-specific opportunities decreases and the difficulty of using the market increases. As such, the benefits of specializing in exploratory R&D decrease. Hence:

H1b (cell 9): Specializing in exploratory R&D has a negative effect on performance when the firm operates in an exploratory-oriented industry.

4.2. The strategy of the focal firm differs from that of its intra-industry peers (cells 2, 3, 7, 8)

Reversing the logic of the previous hypotheses, we expect that when the R&D strategy of the focal firm differs from the strategy of most of its industry peers to be more effective in enhancing its performance. Hence, for several reasons, we contend that specializing in exploitative R&D should enhance the focal firm's performance when it operates in an ambidextrous industry or in an exploratory-oriented industry.

First, the greater availability of exploratory-specific knowledge, capabilities and opportunities in ambidextrous and exploratory-oriented industries means that it is easier for firms that specialize in exploitative R&D to use the market in a way that complements their own exploitative activities (Fleming, 2001). In such cases, they are also more likely to accelerate their learning because they are exposed to a large volume of ideas generated by firms that specialize in exploratory R&D (Morgan & Berthon, 2008). In ambidextrous and exploratory-oriented industries, there is also greater likelihood that the focal firm that specializes in exploitative R&D will collaborate to explore new opportunities (Gupta et al., 2006; Baum et al., 2000).

Furthermore, the knowledge base and outputs of the focal firm differs from that of the majority of firms in the industry, and it is therefore less likely to become redundant or be substituted by that of other firms in the industry (Belderbos & Zou, 2009). In addition, in line with the industry-based perspective that underscores the strategic fit between the firm and its industry, we expect easier access to exploratory knowledge and expertise in ambidextrous and exploratory-oriented industries to enable exploitative firms to internalize exploitation-specific functions while acquiring ideas from the market (Williamson, 1981). Greater availability of exploration-specific opportunities also decreases the difficulty of establishing exploratory-oriented R&D agreements, thus increasing the effects of exploitative R&D on performance. Accordingly, we expect specialization in exploitative R&D to have greater returns in ambidextrous and exploratory-oriented industries. Applying the same logic, we expect specialization in exploratory R&D to be more beneficial when the focal firm operates in an ambidextrous or an exploitative-oriented industry:

H2a&b (cells 2 & 3): *Specializing in exploitative R&D has a positive effect on the performance of the focal firm when it operates* ***a)*** *in an* ambidextrous *industry or* ***b)*** *in an exploratory-oriented industry.*

H3a&b (cells 7 & 8): *Specializing in exploratory R&D has a positive effect on the performance of the focal firm when it operates* ***a)*** *in an* ambidextrous *industry or* ***b)*** *in an exploitative-oriented industry.*

4.3. The focal firm is ambidextrous and operates in an ambidextrous industry (cell 5)

We further hypothesize that being ambidextrous can enhance the focal firm's performance when it operates in an ambidextrous industry. The availability of both exploratory-specific and exploitative-specific knowledge in ambidextrous industries offer ambidextrous firms the opportunity to either explore new ideas and technologies (Uotila et al., 2009) or exploit existing ones, depending on their needs (Banerjee &

Siebert, 2017). The focal firm can also pursue more easily exploitative and exploratory collaborative agreements in ambidextrous industries. Moreover, the effectiveness of those is likely to be stronger given that many firms possess skills, capabilities and knowledge that can complement the activities of the focal firm. Furthermore, when an ambidextrous focal firm operates in an ambidextrous industry, it can accelerate its learning by making a better use of external opportunities and by identifying complementary skills and capabilities (Hess & Rothaermel, 2011). In summary, the availability of both exploratory and exploitative knowledge and expertise in ambidextrous industries helps ambidextrous firms to identify and benefit from collaborative and knowledge-sourcing opportunities without increasing the difficulty of accessing such opportunities. Hence:

H4a (cell 5): *Being ambidextrous has a positive effect on the performance of the focal firm when it operates in an* ambidextrous *industry.*

4.4. The focal firm is ambidextrous while the majority of its industry peers specialize in either exploration or exploitation (i.e., cells 4 and 6)

By contrast, we expect that being ambidextrous and operating in highly specialized industries (either exploratory or exploitative-oriented) affects firm performance negatively. The theoretical justification for this prediction relies on the notion that the value of the ideas and outputs of an ambidextrous firm is likely to be lower in industries that are oriented towards a particular direction (Belderbos & Zou, 2009). The ideas and knowledge developed by other specialized firms in the industry are likely to compete more effectively than those of ambidextrous focal firms. Hence, being ambidextrous in such industries will not provide strong differentiation from competitors (Belderbos & Zou, 2009) and will not significantly enhance the firm's competitive advantages. Put differently, the knowledge, capabilities and outputs of firms that have chosen to specialize are more likely to be distinct. Hence, the ideas and outputs of the ambidextrous focal firm are more likely to become redundant. Accordingly, we expect highly specialized competitors to decrease the performance of ambidextrous focal firms:

H4b (cells 4 & 6): *Being ambidextrous has a negative effect on the performance of the focal firm when it operates in either an exploitative-oriented or explorative-oriented industry.*

5. Data and methods

5.1. Sample

We employ an unbalanced panel dataset of 32,526 observations (5567 firms) over the 2003–2012 period. We collected the data from the PITEC database (Technological Innovation Panel of Spain), which is a large-scale survey that captures the R&D and innovation activities of Spanish firms. It is administered and coordinated by the National Statistics Institute (INE), theFoundation for Technical Innovation (COTEC) and the Foundation for Science and Technology (FECYT) in Spain. As this is a national survey, over 90 % of firms respond, reducing concerns about selection bias. Our analysis focuses on firms with more than ten employees that report information on exploration and/or exploitation for at least four consecutive years. Various characteristics of the Spanish economy make it an appropriate empirical context for our research.

First, while some countries place emphasis on a few sectors only, Spain is a balanced economy that covers a wide range of industries. This is important for our study as we need industry variation to test how the strategy adopted by peers in different industries affects the focal firm's performance. Given that Spain has 56 different industries that make a considerable contribution to the economy, it is ideal for our analysis. Second, there is significant variation in the R&D strategies of Spanish firms. PITEC provides a breakdown of the distribution of firms' budget across exploratory and exploitative R&D (Mavroudi et al., 2020; Barge-Gil & López, 2014) and for several years covering the 2003–2012 period. This allows us to track firms' R&D in each year and how it might change over time.

5.2. Dependent variable

Drawing from the R&D literature, we use *total factor productivity (TFP)* as the primary measure of firm performance (Adams & Jaffe, 1996; Kafouros et al., 2018; Mavroudi et al., 2020), we also use alternative measures (sales growth) to explore the robustness of the results. Starting from our main dependent variable (TFP), in addition to the fact that it is one of the most used measures in the R&D and firm performance literature, there are three other reasons for using TFP. First, TFP relies on a function (described below) that captures the level of *output* (i.e., revenues from products and services) that each firm can generate from a given level of *inputs* (e.g., tangible and human resources). This is important because different firms may use different levels of inputs to generate revenues (Van Beveren, 2012). Hence, it is effective in capturing variations in firm performance that cannot be explained by variations in firm inputs, reflecting the firm's effectiveness in generating value from specific inputs and activities.

Second, TFP reflects that R&D investment can lead not only to new products and services that typically generate revenues, but also to process innovations that lead to efficiency gains. This is important as exploitative R&D often aims at improving efficiency. Third, although measures of profitability are volatile over years, TFP is more stable and is affected to a lesser extent by business cycles, exchange rates and accounting standards. Furthermore, TFP is an appropriate measure from a theoretical point of view as a key premise in the paper is that specialization increases the efficiency with which firms perform specific activities due to accumulated expertise that ultimately enhances performance (Holmqvist, 2004).

To estimate TFP for each firm (i) and each year (t), we need to capture the relationship between certain firm inputs (X) and outputs (Y). This approach is common in the R&D literature (Kafouros & Aliyev, 2016; Kafouros et al., 2018) and in studies that distinguish between exploratory and exploitative R&D (Mavroudi et al., 2020). In this function (equation 1), we capture inputs (X) by the firm's tangible assets (K) and human resources (L), and output (Y) by the revenues generated by the firm's ideas, products and services. T indicates year dummies while (ε) refers to the 'residual' of the function. It is this residual that captures variations in firms' revenues that cannot be explained by variations in firm inputs. This residual therefore is a direct measure of productivity performance that accounts for differences in firm resources and inputs: $Y_{it} = {}_{it} + L_{it} + T_t + \varepsilon_{it}$ *equation (1)*.

Furthermore, in addition to TFP, we used an alternative measure of firm performance to explore the robustness of the results. We operationalized firm performance using *sales growth* which has been used widely in the literature (He & Wong, 2004; Ho et al., 2020). Sales growth is calculated as $\Delta Se(t) = \frac{Se(t)-Se(t-1)}{Se(t)-1}$ where *Se* stands for sales per employee, and the subscript *t* denotes time. As growth occasionally takes negative values, we use the Inverse Hyperbolic Sine (IHS). The IHS transformation is similar to a logarithmic transformation but can deal with negative values while improving the normality of the data (Kafouros & Aliyev, 2016; Burbidge et al., 1988).

5.3. Independent variables

5.3.1. Exploratory and exploitative R&D

Following March's (1991) conceptualisation, we operationalise the two activities by distinguishing the firm's investments in Research (R) from its investments in Development (D). Following established practice (D'Este et al., 2018; Mavroudi et al., 2020), we measure *exploratory R&D* using the firm's annual investment in Basic and Applied Research, while *exploitative R&D* using the firm's annual investment in systematic technological Development. We divided each measure by the number of employees to normalize for firm size and used logs to ease the interpretation of the results (Van Beveren, 2012).

The measures of *exploratory and exploitative R&D* are consistent with studies that differentiate between exploratory and exploitative R&D (D'Este et al., 2018; Swift, 2016), and with the conceptual definitions of exploration and exploitation (March 1991) and R&D (OECD, 2005). In the PITEC survey, firms distinguish their R&D investments in *Basic* and *Applied Research* from *Development* (D'Este et al., 2018; Czarnitzki et al., 2011). Based on the survey's definitions, *Basic Research* captures "experimental or theoretical work that is mainly undertaken to obtain new knowledge on the essentials of observable phenomena and facts, without considering giving them any particular application or use whatsoever". It therefore captures experimental or theoretical activities that create new knowledge on foundations and observable facts (OECD, 2005). *Applied Research* refers to "original work carried out to acquire new knowledge; however, it is mainly directed towards a specific practical objective". It captures activities that involve searching for (exploring) new outcomes and original knowledge (OECD, 2005). Hence, these two answers together correspond to exploratory research activities (i.e., the R component of the R&D) and reflect March's (1991) view of exploration and "search for new ideas".

We measure firms' investment in exploitative R&D using a question in the PITEC survey that asks firms to report their investments in the *Development* component of R&D, which is defined as "…systematic work based on existing knowledge, obtained from the research and/or practical experience" which aims at the establishment of new processes, systems and services, or at the improvement of existing ones. This corresponds to the refinement and exploitative part of such activities (i.e., the D component of R&D), which differs from the *Research* component that was discussed above. As exploitative (*development)* activities focus on the use of existing knowledge and ideas (OECD, 2005), this operationalization of exploitative R&D captures March's (1991) view of activities that build on prior knowledge, lead to the refinement of existing technologies and efficiency, while building on the firm's existing capabilities. Overall, these measures are consistent with March's (1991) view about creating new knowledge through different types of research vis-a-vis exploiting existing knowledge as well as with the definitions provided by OECD (2005). Such measures have also been adopted by several prior studies (Barge-Gil & López, 2014; Czarnitzki et al., 2011; D'Este et al., 2018; Mavroudi et al., 2020).[1]

5.3.2. Specializing in exploratory and exploitative R&D or being ambidextrous

Prior studies on ambidexterity (He & Wong, 2004) use the absolute percentage difference between firms' spending on exploratory and exploitative activities. Given that specialization is a strategy by which firms limit the scope of their activities, we classify a firm as specialized in one R&D activity when it spends over 66.6 % of its internal R&D budget on either exploratory or exploitative activities. This means that a firm's investment in one of the two activities is at least two times higher than its investment in the other activity. This is a year-specific time-variant measure (i.e., it captures changes from one year to the other). This is useful because a firm could specialize in exploratory R&D in one year but not in the next year. We also constructed an average-specific, time-invariant variable of specialization by estimating the average percentage of each firm's budget spent on exploratory and exploitative R&D throughout the sampled years. This classification ensures that a firm remains specialized in one activity over a long period of time (rather than for just 2–3 years). We accordingly created one variable for specialization in *exploratory R&D* and one for specialization in *exploitative R&D* (which take the value of 1 when a firm specializes in one of the two activities; and 0 otherwise). When a firm's spending on one activity is between 33.3 % and 66.6 %, it was categorized as ambidextrous.

5.3.3. Industry orientation: Ambidextrous, exploitative-oriented and exploratory-oriented

To capture *industry orientation,* we first classified each firm in an industry as ambidextrous, exploratory or exploitative (using the approach described in the previous section). Using this information, we estimated the percentage that each of these three categories represents in each industry. Second, we estimated for each industry the absolute percentage difference between firms that specialize in exploratory R&D and those that specialize in exploitative R&D. For example, 49 % of firms in the agriculture industry specialize in exploratory R&D and 25 % in exploitative R&D. Third, we used the median of this percentage difference (which was 20 %) to identify industries that were oriented towards one of the two activities. For instance, the absolute difference was 24 % in the agriculture industry. Hence, we classified it as exploratory-oriented. Industries that were not oriented towards one activity were classified as ambidextrous. Based on this categorization, we create three dummy variables that take the value of 1 when an industry is ambidextrous or oriented towards exploitative or exploratory R&D.

In exploitative-oriented industries, 51 % of firms (on average) specialize in exploitative R&D while only 21 % of firms specialize in exploratory R&D. By contrast, in exploratory-oriented industries 47 % of firms specialize in exploratory R&D and only 21 % of firms in such industries specialize in exploitative R&D. In ambidextrous industries, there is a similar distribution of firms that either specialize in exploratory/exploitative R&D or are ambidextrous. Exploitative-oriented industries include sectors such as telecommunication, machinery, mechanical equipment, electrical, motor vehicles and computing. The pharmaceutical, extractive, health-related and chemicals sectors are exploratory-oriented. Ambidextrous industries include sectors such as textiles, petroleum refining, electricity and minerals.

5.3.4. Firm-industry combinations

To test the hypotheses, we use the combinations presented in Table 1. Each cell represents one of the nine possible combinations of the strategy of the focal firm and its operation in industries that are exploratory-oriented, ambidextrous or exploitative-oriented. Focal firms that specialize in exploitative R&D and operate in an exploitative-oriented, ambidextrous or exploratory-oriented industry are represented by cells 1, 2, 3. Ambidextrous focal firms that operate in exploitative-oriented, ambidextrous and exploratory-oriented industries are represented by cells 4, 5, 6. Specialized in exploratory R&D firms that operate in exploitative-oriented, ambidextrous or exploratory-oriented industries fall into cells 7, 8 and 9 respectively. Accordingly, we created nine dummy variables that take the value of 1 when a firm belongs to one of these nine cells, representing therefore all the possible combinations.

5.4. Control variables

Our analysis controls for several factors at the firm and industry level. We initially controlled for *tangible assets* (Auh & Menguc, 2005; Jansen et al., 2006) to account for difficulties that resource-constrained firms typically face in different industries (Hannan & Freeman, 1984). This variable is measured as the log of each firm's tangible assets divided by the number of employees to normalise for firm size. We further accounted for firms that are *newly created* using a dummy variable that takes the value of 1 if a firm is four or less than four years old (Laursen & Salter, 2006) because new vis-à-vis established firms may differ in their ability to utilize and establish collaborations or source knowledge. We also accounted for each firm's expansion abroad (*international sales)*, using a dummy variable for those firms that sell overseas. We accounted for this variable because international sales can affect a firm's growth (He & Wong, 2004), international competitiveness and access to

[1] The measures capture exploratory and exploitative R&D activity, rather than radical and incremental innovations.

Table 2
Descriptive Statistics Correlations.

	1	2	3	4	5	6	7	8
1 Total Factor Productivity								
2 Exploitative Firms in Exploitative Industries (Cell 1)	−0.036***							
3 Exploitative firms in Hybrid Industries (Cell 2)	0.077***	−0.121***						
4 Exploitative Firms in Exploratory Industries (Cell 3)	−0.041***	−0.103***	−0.121***					
5 Ambidextrous Firms in Exploitative Industries (Cell 4)	−0.044***	−0.082***	−0.097***	−0.082***				
6 Ambidextrous Firms in Hybrid Industries (Cell 5)	0.068***	−0.106***	−0.124***	−0.106***	−0.085***			
7 Ambidextrous Firms in Exploratory Industries (Cell 6)	−0.048***	−0.121***	−0.143***	−0.121***	−0.097***	−0.125***		
8 Exploratory Firms in Exploitative Industries (Cell 7)	0.013**	−0.067***	−0.079***	−0.067***	−0.054***	−0.069***	−0.079***	
9 Exploratory Firms in Hybrid Industries (Cell 8)	0.064***	−0.126***	−0.147***	−0.125***	−0.100***	−0.129***	−0.148***	−0.082***
10 Exploratory Firms in Exploratory Industries (Cell 9)	−0.049***	−0.175***	−0.206***	−0.175***	−0.140***	−0.180***	−0.207***	−0.114***
11 Exploratory R&D	−0.050***	0.288***	0.216***	0.240***	0.215***	0.157***	0.248***	−0.174***
12 Exploitative R&D	−0.059***	−0.307***	−0.532***	−0.364***	0.169***	0.098***	0.198***	0.145***
13 Tangible Assets	0.207***	0.041***	0.028***	−0.054***	0.051***	0.055***	−0.053***	0.040***
14 International Sales	0.240***	−0.004	0.009*	0.001	0.007	−0.007	0.022***	−0.014***
15 Affiliated Firms	0.328***	0.004	−0.007	−0.039***	0.009*	0.028***	−0.021***	−0.003
16 Industry Competition	0.055***	0.114***	−0.027***	0.002	0.101***	−0.040***	−0.016***	0.075***
17 Protection	0.131***	0.035***	−0.020***	−0.017***	0.045***	0.016***	0.008*	−0.002
18 Newly Created Firms	−0.066***	−0.001	−0.008	−0.006	0.021***	−0.013**	0.016***	0.007
19 High Tech Firms	0.142***	0.309***	−0.193***	0.010**	0.220***	−0.163***	0.019***	0.210***
20 Knowledge spillovers	−0.222***	0.123***	−0.166***	0.093***	0.132***	−0.187***	0.082***	0.082***
21 External R&D services	0.052***	0.050***	−0.092***	−0.036***	0.093***	0.028***	0.055***	0.019***
Mean	0.059	0.096	0.121	0.090	0.066	0.101	0.125	0.043
Std. Dev.	0.937	0.295	0.326	0.286	0.248	0.301	0.331	0.203
Min	−11.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	5.529	1	1	1	1	1	1	1

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

knowledge (Cassiman & Veugelers, 2006). Further, we created a dummy variable (*affiliated firms*) to account for differences between affiliated and non-affiliated firms because firms affiliated with a group have access to advantages and resources that might improve their performance compared to their non-affiliated counterparts (Chang & Hong, 2000).

The way in which firms protect their products and technologies may also affect their performance (Laursen & Salter, 2006). To account for this, we created a variable that captures the *protection* that each firm uses (i.e., use of patents, utility models, trademarks and copyrights). This logged variable ranges from 0 to 4, depending on how many of these mechanisms each firm employs. In addition, we captured each firm's annual spending on *external R&D services* to account for variations in knowledge sourcing and external agreements. This variable (again in logs) captures each firm's purchase of external R&D services through different means including acquisition, contracts and agreements pertaining to knowledge, patents and other technologies.

We also control for several industry-specific attributes. We control for each industry's level of *competition* using the Herfindahl Index (HI) (Kafouros & Aliyev, 2016; Mavroudi et al., 2020): $CI_j = 1 - \sum_{i=1}^{n} s_{ij}^2$, where s_{ij} is the market share of firm i in industry j and therefore it takes values between 0 and 1. We use the inverse value of the Herfindahl Index (i.e., higher value indicates a higher level of competition). Further, we control for *intra-industry knowledge spillovers*. This measure is estimated by subtracting the focal firm's total R&D expenditure from the total R&D expenditure of the firm's industry. This is a commonly used approach (Kafouros et al., 2018). This variable is logged and normalised for firm size. To account for variations in industry dynamics, we included a dummy variable (*high-tech industries)* that distinguishes firms that operate in high-tech industries (e.g., pharmaceutical, computing and electronics) from firms in low-tech industries (such as textiles, furniture). Finally, we incorporated *year dummies* to account for differences in economic trends and business cycles.

5.5. Estimation method

As firms in our sample are nested within industries, we use the Multilevel mixed-effect estimator, which is also known as Hierarchical Linear Model (HLM) estimator (Preacher et al., 2006; Anderson, 2019). This estimator enables us to specify the model at different levels and can therefore yield coefficients that are clustered in different levels (industry and firm). This is important because the multi-industry context of our analysis means that the nature and intensity of exploratory/exploitative R&D may vary across industries. Furthermore, while traditional panel data estimators usually calculate either Fixed Effects (FE) or Random Effects (RE), using multilevel mixed effects has the advantage of using both FE and RE as they are estimated for each firm (and within a given industry) separately (Blundell & Bond, 2000). Hence, it provides an estimation that is close to FE whilst maintaining the assumption of independence of error terms that is typically violated when firms operate in different industries (Hox et al., 2017; Preacher et al., 2006). However, to ensure that the results are not biased by a specific estimator, we used the generalized least squares (GLS) estimator.

We also experimented with FE and RE estimators. Although the FE estimator may be more efficient than the RE estimator by allowing individual specific effects to be correlated with the independent variables (Wooldridge, 2010), the use of FE is suitable only for time-varying regressors. Because key variables (e.g., industry orientation and firm specialization) either do not exhibit high levels of time variance (or are time-invariant), its use is less appropriate. Overall, the use of the multilevel mixed effect estimator is appropriate because it allows us to specify the nested coefficients while it relies on the assumption of independence of errors. Finally, to address endogeneity concerns, we employed the two-stage least squares (2SLS) estimator (which is described in detail in the robustness section).

6. Results

6.1. Main results

Table 2 presents the descriptive statistics. The correlations are at acceptable levels and the variance inflation factor (VIF) further validates the absence of multicollinearity with values well below the accepted cut-off point of 10 (Wassmer et al., 2017). Table 3 reports the regression results using the Multilevel mixed-effect estimator for both the year-specific and average-specific estimation of specialization. Model 1 serves as the baseline model. In Models 2 and 3, the specialization

9	10	11	12	13	14	15	16	17	18	19	20	21
−0.213***												
−0.452***	−0.517***											
0.170***	0.352***	−0.221***										
0.021***	−0.080***	0.086***	0.045***									
0.008	−0.021***	0.020***	0.003	0.069***								
0.008*	0.015***	−0.031***	0.003	0.091***	0.102***							
−0.056***	−0.066***	0.056***	−0.041***	0.038***	0.146***	−0.015***						
−0.022***	−0.022***	0.054***	0.023***	0.082***	0.171***	0.141***	0.104***					
−0.006	−0.004	0.028***	0.033***	0.021***	−0.052***	−0.002	−0.003	−0.018***				
−0.202***	−0.032***	0.129***	0.005	0.027***	0.134***	0.031***	0.170***	0.092***	−0.013**			
−0.217***	0.109***	0.197***	0.188***	−0.060***	−0.068***	−0.327***	0.320***	−0.125***	0.048***	0.157***		
−0.063***	−0.012**	0.224***	0.251***	0.153***	0.028***	0.092***	−0.002	0.092***	0.018***	0.051***	0.097***	
0.132	0.226	4521.633	4969.747	8706656.000	0.767	0.466	0.924	0.583	0.006	0.217	6568679.000	1677.715
0.339	0.418	21089.830	17349.080	86200000.000	0.423	0.499	0.089	0.792	0.076	0.412	11900000.000	12308.220
0.000	0.000	0.000	0.001	17.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
1	1	2,371,429	1,489,540	3,000,000,000	1	1	0.988	4	1.000	1	186,000,000	740,323

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

variable relies on a year-specific estimation (i.e., it is measured every year). Models 4 and 5 are similar to Models 2 and 3 but rely on the average-specific estimation of specialization (which is based on the average of all years for each firm).

Models 2 and 4 test how performance is influenced when firms that specialize in exploitative R&D operate in an exploitative-oriented industry (cell 1), when ambidextrous firms operate in exploitative-oriented (cell 4) and exploratory-oriented industries (cell 6), and when firms specialize in exploratory R&D and operate in an exploratory-oriented industry (cell 9). Models 3 and 5 test these effects when firms specialize in exploitative R&D and operate in ambidextrous industries (cell 2) and exploratory-oriented industries (cell 3), for ambidextrous firms in an ambidextrous industry (cell 5), and for firms that specialize in exploratory R&D and compete in an exploitative-oriented (cell 7) and ambidextrous industry (cell 8).

Overall, the results confirm most of the theoretical predictions. Models 2 and 4 indicate that specializing in exploitative R&D affects firm performance negatively when firms operate in exploitative-oriented industries. The results therefore corroborate H1a. The results yield a similar pattern when the opposite case is considered, i.e., specializing in exploratory R&D has a negative effect on performance when the focal firm operates in an exploratory-oriented industry. They therefore support H1b and the theoretical prediction that firm advantages become partially redundant when they are offered by several other firms within the industry.

Models 3 and 5 test H2a and H2b. Specializing in exploitative R&D enhances firm performance when firms compete in ambidextrous industries (cell 2), providing support for H2a. The corresponding effects of this specialized strategy are also positive as expected when firms operate in exploratory-oriented industries (cell 3), but they are statistically insignificant. Hence H2b is not supported. A similar pattern in the results emerges when we consider the effects of specializing in exploratory R&D. This strategy enhances performance when firms operate in ambidextrous industries (cell 8), supporting H3a. However, the corresponding effects are statistically insignificant for H3b, suggesting that specializing in exploratory R&D is beneficial when firms compete in exploitative-oriented industries.

Models 2–5 test H4a and H4b. These hypotheses suggest that being ambidextrous has a positive effect on performance when the firm operates in an ambidextrous industry (cell 5) and a negative effect when the firm operates in either an exploitative-oriented or explorative-oriented industry (cells 4 and 6). The results in Models 2–5 fully support these predictions. In Models 2 and 4, the coefficients for the relevant hypotheses are negative when firms are ambidextrous and operate in either exploitative-oriented or explorative-oriented industries. By contrast, the corresponding coefficients in Models 3 and 5 are positive when ambidextrous firms operate in ambidextrous industries. Hence, the results support H4a and H4b.

Overall, the empirical analysis suggests that firm strategies are less beneficial when firms operate in industries that exhibit an orientation that is similar to their own strategy. However, a specialized strategy in either exploratory or exploitative R&D is advantageous for firms that compete in ambidextrous industries. Although the results are statistically insignificant when we test whether specialized firms benefit from operating in industries with an orientation that is dissimilar to their own strategy, the results overall suggest that the comparative advantages of specialized strategies are more prominent when they complement the orientation of the industry.

6.2. Robustness checks

First, to confirm that the results are not the outcome of a particular approach, we re-run the models using the *Generalized Least Squares (GLS)* estimator as an alternative to the multi-level mixed effect approach. The new results are consistent to those reported in Table 3, and in some cases, they improve in terms of strength and statistical significance. For instance, the coefficient for cell 6 improved its statistical significance from 10 % to 5 % and cell 3 became statistically significant at 10 %. Second, we examined the sensitivity of the results to changes in the operationalization of "firm specialization". Instead of categorizing firms that spend over 66.6 % of their R&D budget on either exploratory or exploitative R&D as "specialized", we used the 75 % threshold. Once again, the findings were consistent with those reported in Table 3.

Third, to account for the fact that exploratory investments may require time to be implemented and materialize (March 1991), we experimented with time lags (1 and 2 years). The hypothesized results remained qualitatively similar. Four, rather than using the number of

Table 3
Regression Results (Multilevel Mixed Estimator).

	Model 1 TFP (YS)	Model 2 TFP (YS)	Model 3 TFP (YS)	Model 4 TFP (AS)	Model 5 TFP (AS)	Model 6 sales growth (YS)	Model 7 sales growth (YS)	Model 8 sales growth (AS)	Model 9 sales growth (AS)
H1a: Specializing in exploitative R&D in exploitative-oriented industries (Cell 1)		−0.083***		−0.509***		-0.019†		-0.018†	
		(0.023)		(0.053)		(0.011)		(0.011)	
H1b: Specializing in exploratory R&D in exploratory-oriented industries (Cell 9)		−0.027†		−0.261***		-0.021*		-0.024**	
		(0.017)		(0.028)		(0.009)		(0.008)	
H2a: Specializing in exploitative R&D in hybrid industries (Cell 2)			0.498***		0.519***		0.04***		0.034**
			(0.034)		(0.041)		(0.012)		(0.011)
H2b: Specializing in exploitative R&D in exploratory-oriented industries (Cell 3)			0.028		0.051		0.006		−0.007
			(0.019)		(0.041)		(0.012)		(0.011)
H3a: Specializing in exploratory R&D in hybrid industries (Cell 8)			0.452***		0.432***		0.026*		0.02*
			(0.031)		(0.040)		(0.01)		(0.01)
H3b: Specialized in exploration firms in exploitative-oriented industries (Cell 7)			−0.007		−0.051		0		0.01
			(0.025)		(0.063)		(0.014)		(0.017)
H4b: Ambidextrous firms in exploitative-oriented industries (Cell 4)		−0.095***		−0.466***		−0.012		−0.017	
		(0.025)		(0.059)		(0.014)		(0.013)	
H4a: Ambidextrous firms in hybrid industries (Cell 5)			0.455***		0.450***		0.04***		0.045***
			(0.032)		(0.042)		(0.012)		(0.01)
H4b: Ambidextrous firms in exploratory-oriented industries (Cell 6)		−0.031†		−0.323***		-0.033***		-0.021*	
		(0.016)		(0.036)		(0.010)		(0.009)	
Exploratory R&D	0.002*	0.004*	0.001	0.003*	0.002*	0.001	0	0	0
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Exploitative R&D	0.002†	0.003*	0.006**	0.003*	0.003*	0.002	0.002	0.001	0.001
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Tangible Assets	−0.001	−0.002	−0.002	−0.002	−0.002	0.025***	0.025***	0.026***	0.025***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
International Sales	0.052***	0.052***	0.051***	0.051***	0.050***	0.001	−0.001	0	0
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.008)	(0.008)	(0.008)	(0.008)
Affiliated Firms	0.126***	0.127***	0.130***	0.129***	0.131***	0.066***	0.068***	0.067***	0.068***
	(0.015)	0.015***	(0.015)	(0.015)	(0.015)	(0.006)	(0.006)	(0.006)	(0.006)
Industry Competition	0.263*	0.266*	0.231*	0.254*	0.229*	-0.126**	-0.132**	-0.128**	-0.136***
	(0.112)	(0.112)	(0.112)	(0.112)	(0.112)	(0.041)	(0.041)	(0.041)	(0.041)
Protection	0.004**	0.004**	0.004**	0.004**	0.004**	-0.005***	-0.004***	-0.004***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Newly Created Firms	−0.317***	−0.316***	−0.319***	−0.317***	−0.320***	0.096	0.097	0.096	0.097
	(0.090)	(0.090)	(0.090)	(0.090)	(0.090)	(0.093)	(0.093)	(0.093)	(0.093)
High Technological Firms	0.266***	0.294***	0.462***	0.430***	0.463***	0.006	0.015*	0.007	0.014†
	(0.025)	(0.027)	(0.028)	(0.031)	(0.028)	(0.007)	(0.007)	(0.007)	(0.007)
Knowledge spillovers	0.009	0.009	0.029**	0.020*	0.029**	0.007**	0.009***	0.007***	0.009***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.002)	(0.002)	(0.002)	(0.002)
External R&D services	0.002**	0.002**	0.002**	0.003**	0.003**	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Time Effects	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Number of observations	32,526	32,526	32,526	32,526	32,526	32,525	32,525	32,525	32,525
Number of Firms	5567	5567	5567	5567	5567	5567	5567	5567	5567

*p < 0.05; **p < 0.01; ***p < 0.001; †p < 0.10.
Notes: 1) Standard errors are reported in parentheses; 2) **YS** in the models refers to Year-Specific Specialization while **AS** refers to Average-Specific Specialization.

firms (i.e., concentration) in each industry to classify industry orientation, we used a classification based on the overall investment in exploration and exploitation in each industry. We categorize industries as exploitative- or exploratory-oriented when they spend over two thirds of their internal R&D budget on either of these two activities. The re-estimated results using this classification led to similar effects for the hypotheses as those reported in Table 3.

Fifth, to check the robustness of our results, we used sales (normalized for firm size) as an alternative dependent to TFP. The results corroborate the key findings, and some hypotheses improved their statistical significance. In addition, following the literature (He & Wong, 2004), we used *sales growth* as an alternative dependent variable (see Models 6 to 9 in Table 3). The results are largely similar to the main results reported in Table 3 (although the level of statistical significance changed for some coefficients). Finally, to account for the fact that some firms have better access to various resources and advantages compared to other firms, in addition to controlling for 'group affiliation', we added a 'foreign owned' dummy variable to the model, which takes the value of 1 when foreign participation (ownership) is equal or above 50 % (Kafouros & Aliyev, 2016). The new results are consistent with the main results and the statistical significance further improved in H1b and H4b.

6.3. Endogeneity tests

Endogeneity typically arises from omitted variables, measurement errors, simultaneity problems (i.e., reverse causality) and discrepancy between the variables and their proxies (Wooldridge, 2010). Simultaneity might arise in our study due to the endogenous nature of R&D investments (Hamilton & Nickerson, 2003; Kafouros et al., 2018). This implies that managerial decisions to invest in either type of R&D are not random, but rather endogenous and often driven by expected performance outcomes (Hamilton & Nickerson, 2003). In such instances, causality may run in both directions (Bascle, 2008). Since it is not clear whether well-performing firms choose to specialize in a specific type of R&D (or are ambidextrous), we treat endogeneity considering the firm's exploratory and exploitative R&D as endogenous regressors.

To do so, we re-run the models using the two-stage least squares (2SLS) (Wooldridge, 2010; Bascle, 2008; Ho et al., 2020). The 2SLS approach relies on finding instruments that are not correlated with the error term to predict a proxy for potentially endogenous regressors in the first stage. In the second stage, we use the predicted values to estimate the Multilevel mixed-effect model (Wooldridge, 2010; Bascle, 2008). We selected three instrumental variables: the number of *intra-industry competitors*; the *total sales* of each industry and the *total industry's innovation spending*. The choice of these variables was based on the fact that although they may affect exploratory and exploitative R&D investments, they are exogenously determined by market, regulatory and other institutional forces but they are not explicitly related to the error term (Hamilton & Nickerson, 2003). The first stage regression results confirmed that the chosen instruments are good predictors ($R^2 = 0.76$ and 0.73 for exploratory and exploitative R&D respectively). Further, the Durbin chi2(2) = 2962.33 (p = 0.0000) and the Wu-Hausman F (2,32496) = 1628.08 (p = 0.0000) and F statistic for both exploratory R&D (72.421) and exploitative R&D (92.169) validated that the selected instruments are appropriate. Using the 2SLS approach, we re-estimated the models. Overall, the new results are similar to the results reported in Table 3 (the only exception is that the coefficient of cell 6 loses its significance).

Table 4
Additional analysis (Multilevel Mixed Estimator).

	Model 1 (cells 2, 3, 5, 7 and 8)	Model 2 (cells 1, 4, 6 and 9)
Exploratory R&D	0.004*	−0.001
	(0.002)	(0.002)
Exploitative R&D	0.004*	0.008*
	(0.001)	(0.003)
Tangible Assets	−0.010**	0.006
	(0.003)	(0.004)
International Sales	0.074***	0.050*
	(0.016)	(0.020)
Affiliated Firms	0.152***	0.144***
	(0.021)	(0.021)
Industry Competition	0.276	0.238†
	(0.173)	(0.141)
Protection	0.007***	0.004*
	(0.002)	(0.002)
Newly Created Firms	−0.423**	−0.221*
	(0.141)	(0.104)
High Technological Firms	0.116**	0.471***
	(0.039)	(0.030)
Knowledge spillovers	**0.039****	**−0.031***
	(0.012)	(0.012)
External R&D	**0.026***	**0.011**
	(0.011)	(0.014)
Time Effects	incl.	incl.
Knowledge Spillovers X External R&D	−0.001*	−0.001
	(0.001)	(0.001)
Firm Variance	0.757	0.617
	(0.037)	(0.031)
Residual Variance	0.102	0.139
	(0.008)	(0.010)
Number of observations	15,847	16,679
Number of Firms = 5,567	3576	3292

*p < 0.05; **p < 0.01; ***p < 0.001; †p < 0.10. Standard errors are reported in parentheses.

6.4. Additional analyses

Our framework suggests that firms that specialize in exploratory or exploitative R&D can use the market to access complementary knowledge, inputs and skills. A lower degree of similarity between external knowledge and a firm's own knowledge (i.e., in cells 2, 3, 5, 7 and 8) increases complementarities and creates new opportunities (Fleming, 2001). This reasoning suggests that knowledge spillovers in industries that differ in their orientation from that of the firm's own specialization are more beneficial than cases in which the firm operates in an industry with a similar orientation to its strategy. If this logic is valid, we would expect *the role of external knowledge spillovers in enhancing the performance of the focal firm in cells 2, 3, 5, 7 and 8 to be stronger than in cells 1, 4, 6 and 9*. The above reasoning also applies to the case of external R&D opportunities. Accordingly, we would expect *the role of external R&D in enhancing the performance of the focal firms to be stronger in cells 2, 3, 5, 7 and 8 than in cells 1, 4, 6 and 9.*

To test the validity of these predictions and theoretical mechanisms, we first created a variable of *external R&D services* to capture each focal firm's annual spending on exploratory and exploitative R&D services through knowledge and technology acquisitions and agreements. Second, following the established practice in prior studies (Kafouros et al., 2018), we developed a measure of intra-industry knowledge spillovers for each industry. We then used split-sample analysis and estimated the impact of these two measures on the performance of focal firms that fall in cells 2, 3, 5, 7 and 8 vis-à-vis firms that fall in cells 1, 4, 6 and 9.

Models 1 and 2 in Table 4 report these results using the multilevel estimator. The results corroborate our predictions, indicating that the effects of external R&D and knowledge spillovers have stronger (positive) effects on the performance of focal firms in cells 2, 3, 5, 7 than in cells 1, 4, 6 and 9. These results are similar when the GLS estimator is used. Furthermore, in line with the reasoning of our framework which suggests that opportunities for engaging in external R&D are more abundant in some industries, we expect engagement in external R&D to be stronger for focal firms that operate in cells 2, 3, 5, 7 and 8 than in cells 1, 4, 6 and 9. To test this prediction, we run a model (not shown in the table) that sets *external R&D services* as dependent variable. This analysis confirmed that focal firms in cells 2, 3, 5, 7 and 8 spend much more on external R&D services than firms in cells 1, 4, 6 and 9, supporting the prediction that pursuing external R&D opportunities is more difficult in some industries than in others.

Finally, we examined whether productivity moderates the effects of R&D strategies. This analysis indicates that productivity negatively moderates the relationship between *exploratory* R&D strategies and sales growth, but it positively moderates the relationship between *exploitative* R&D strategies and sales growth. No statistically significant results were obtained for ambidextrous R&D strategies. These results are consistent with the view that productivity may negatively affect exploratory activities given that they require experimentation.

7. Discussion and conclusion

7.1. Theoretical contributions

This study makes three contributions to research on exploration/exploitation and firm performance. First, prior research that examines the role of ambidexterity (He & Wong, 2004; Wenke et al., 2021) considers how it is influenced by firm-specific idiosyncrasies (Cao et al., 2009) and market conditions (Auh & Menguc, 2005; Osiyevskyy et al., 2020). Yet, it has paid little attention to how the strategic choices of other firms in the industry influence the effects of each R&D strategy on firm performance (Kafouros et al., 2022). In addressing this omission, the study's first theoretical contribution lies in providing a new explanation of why the effects of ambidextrous and specialized R&D strategies on firm performance differ across industries (and in clarifying how they differ). Specifically, it shows that firm performance is not merely determined by the R&D strategy of the firm, but also by the strategy adopted by the firm's potential competitors and collaborators. This contribution underscores the value of capturing the *combination* between a firm's own R&D strategy and that of its intra-industry peers.

To this end, our framework predicts that a firm's chosen R&D strategy increases its performance when it differs from the strategy adopted by intra-industry peers, while (in contrast) it decreases a firm's performance when it is similar to the R&D strategy of its peers. This effectively means that, for example, an exploitative R&D strategy is beneficial when intra-industry firms specialize in exploratory R&D but becomes less advantageous when most other firms specialize in exploitative R&D. These asymmetric effects occur because the R&D strategies of other firms in the industry facilitate or impede certain opportunities, alter the competitive advantages of the focal firm and, in turn, influence the relationship between ambidexterity/specialization and firm performance. Hence, capturing what strategy most firms adopt helps us clarify which R&D strategy (ambidextrous or specialized) and why is more advantageous for firm performance in each industry.

Second, combining insights from organisational learning (March 1991) and industry-based perspectives (McGahan & Porter, 1997; Rumelt, 1991), another theoretical contribution concerns the explanation of *why* the effects of an R&D strategy can change completely when it is pursued in different industries. This contribution is rooted in showing that such effects are driven by two key mechanisms: a) the availability of external opportunities and expertise in an industry and b) the effectiveness of such opportunities and expertise in increasing performance. These two mechanisms and the notion of 'industry R&D orientation' as developed in the study have implications for how intra-industry competition should be conceptualized and measured (Bain, 1968; Rumelt, 1991). The literature often implicitly assumes that all firms within an industry are competitors. Although firms in an industry might compete, we show that what also matters is that many of these firms conduct exploitative and/or exploratory activities that complement a focal firm's own activities, enhancing therefore its performance.

To this end, we extend prior studies by considering how useful and effective the focal firm's R&D strategy is within the context of its industry. Our analysis does not necessarily contradict the view that ambidexterity is beneficial, but it shows that ambidexterity should be considered not only in the context of each firm (Zhang et al., 2017; Lavie et al., 2011), but also in the wider context of the industry (Gupta et al., 2006). We show that (and clarify why) firms perform better in industries where there are rich opportunities to collaborate and source knowledge to complement their activities. This view emphasizes that positional advantages using the right combinations of strategies lead to superior performance and assist in managing certain trade-offs in ambidexterity (Kim et al., 2012; Zhang et al., 2017).

Third, we contribute to organizational learning research (Levinthal & March 1993; Huber, 1991) by clarifying in what contexts exploratory and exploitative activities matter the most for enhancing firm performance. Specifically, organizational learning theory underscores the importance of exploratory and exploitative activities and their knowledge requirements, objectives (discovery versus efficiency) and performance outcomes. However, the theory does not specify how the strategic behaviour of other firms affects the value of such activities. We demonstrate that specializing in exploratory and exploitative R&D has a performance-enhancing effect when there is knowledge dissimilarity between the industry's orientation and a firm's own R&D strategy. By contrast, there is a performance-weakening effect when there is an overlap between an industry's R&D orientation and a firm's strategy. These findings also extend a central tenet in the competitive dynamics literature (Chen & Miller, 2012), showing that various outcomes are driven not only by the actions of the focal firm, but also by the (re)actions of other firms in its environment and, importantly, by the interactions between the two.

7.2. Managerial implications

Our analysis provides managerial implications both for the focal firm and other firms in the industry. First, we show that the performance effects of ambidextrous and specialized R&D strategies are completely different across industries. Managers must consider their own R&D strategy vis-à-vis that of other firms *simultaneously* and seek to minimize the overlap between the two. An R&D strategy (either exploratory or exploitative) may lead to inferior performance if it is conducted in an industry in which most firms pursue a similar strategy. Our study therefore brings managerial choice to the forefront, showing that closer attention should be paid to specific *combinations* between a firm's R&D strategy and those adopted by most firms.

Second, the study can help managers decide which R&D strategy the firm should adopt (exploratory or exploitative) and in which industries it is more advantageous. A clear implication is that firms should specialize in exploitative R&D when they operate in exploratory-oriented industries, and conversely, they should specialize in exploratory R&D when they operate in exploitative-oriented industries. This point highlights that firms will be in a more advantageous position when they invest in activities that complement those of their industry peers. It also emphasizes that a firm's competitive advantage lies in understanding the potential of some industries to complement its knowledge and expertise. Hence, a key prescription to managers is that although ambidexterity can be useful, the challenges that arise when firms specialize in one activity can be offset by the opportunities offered in the industry.

Finally, our analysis has implications not only for the focal firm, but also for other firms and the entire industry. Firm strategies are dynamic and change over time. As a result, an R&D strategy that might appear to be appropriate can become sub-optimal if the majority of other firms choose to change their R&D strategy. Given that such strategic choices are not coordinated collectively by firms (i.e., each firm individually chooses its R&D strategy), all firms in the industry should carefully monitor how the dominant R&D strategy in their industry changes and make sure that their own strategy remains different and complements that of other firms. Importantly, the way in which a firm positions its R&D strategy vis-à-vis that of its industry peers will determine whether other firms will likely be its competitors (when the adopted strategy is similar) or collaborators (when the adopted strategies are dissimilar).

7.3. Limitations and future research

Future research can advance this study in several ways. First, our analysis focused on how specialized and ambidextrous R&D strategies affect firm performance in different industry contexts. Rather than focusing on performance, a fruitful avenue for future research would be to examine how different combinations of R&D strategy and industry contexts influence various dimensions of firm innovativeness such as the introduction of (or sales from) new technologies, products and services. It might be the case that some combinations are more beneficial for firm innovativeness while other combinations are more advantageous for enhancing firm performance. Furthermore, while we accounted for collaborative opportunities in each industry, future studies can collect data on alliances to examine how different types of collaborations affect the performance and/or innovation advantages of each R&D strategy.

Second, future research can examine how other contextual factors and industry contingencies (beyond industry orientation) influence the ambidextrous and specialized R&D strategies and, in turn, firm performance. Such contingencies may include the type and nature of technology and the strength of intellectual property (IP) protection. For instance, strong legal regimes may matter more to firms that specialize (rather than being ambidextrous) because of their greater need to engage in collaboration and contractual agreements with other firms (while ambidextrous firms can be more self-reliant). Similarly, although strong legal regimes enable firms to protect their inventions (Teece, 1986), weak legal regimes lead to knowledge leakage (Kafouros & Forsans, 2012). Hence, firms that specialize in one activity can access knowledge and inputs more easily when they operate in industries with weak IP protection.

Finally, while we tested our framework using a sample of firms in Spain, a useful research avenue would be to examine our predictions in a more international context and across multiple countries, some of which might be developed or emerging economies. Depending on their development, countries may exhibit different institutional environments and innovation frameworks that may in turn change the relationship between R&D strategies and performance outcomes. It will therefore be useful for future research to explore how variations across countries affect the advantages of ambidextrous and specialized R&D strategies.

7.4. Concluding remarks

A key conclusion from the study is that the effects of ambidextrous and specialized R&D strategies on firm performance are influenced by whether the R&D strategies of other firms are similar to that of the focal firm. An industry's R&D orientation influences two key mechanisms (the availability of collaborative/knowledge-sourcing opportunities and the value of such opportunities) that affect the performance of the focal firm. The empirical analysis shows that for a chosen R&D strategy, some industries offer a greater number of collaborative opportunities, allowing a firm to access knowledge that complements its R&D activities and thereby enhance its performance. Hence, a focal firm's R&D strategy is more advantageous when it differs from the strategy adopted by the majority of its intra-industry peers. By contrast, when the focal firm operates in an industry in which most firms adopt a similar R&D strategy, the overlap of such activities decreases the effectiveness of such strategy in enhancing firm performance. Therefore, the study explicitly shows how the advantages of a focal firm's strategy change depending on the strategic choices of other firms. It thus helps us understand which R&D strategy (ambidextrous or specialized) firms should pursue in each industry.

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CRediT authorship contribution statement

Eva Mavroudi: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Effie Kesidou:** Writing – review & editing, Supervision. **Krsto Pandza:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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