R&D MANAGEMENT

Exploring the dynamics of openness and formal appropriability and its impact on innovation performance in start-ups

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A tension between openness and formal appropriability (FA) emerges in start-ups as they require both in order to attract investors or innovation partners, yet their limited resources are a challenge in this pursuit. This paper sheds light on this tension through the study of the dynamics of openness and formal appropriability over time and the impact of combining openness and formal appropriability mechanisms (FAMs) on innovation performance. Using a longitudinal panel sample of Spanish start-ups during a period of ten years, it is found that start-ups change their openness and formal appropriability strategies over their development and that a combination of openness and formal appropriability enhances start-ups' innovation performance. This combinative strategy is more relevant for start-ups during the early years of start-up growth, and if they have a high R&D intensity. The study contributes to literature that analyses the trade-off between openness and appropriability, and bridges entrepreneurship and open innovation literatures, providing valuable implications for managers.

1. Introduction

Start-ups are often viewed as a source of innovation and economic growth (Shane and Venkataraman, 2000; Calvino et al., 2016), but they experience more severe shortcomings than larger, established firms in terms of human and financial resources (Neyens et al., 2010; Gimenez-Fernandez et al., 2020; Drnevich and West, 2021), and they also lack in reputation and legitimacy (Neyens et al., 2010).

Collaborative strategies to explore and exploit business opportunities (Burgelman and Hitt, 2007) could aid start-ups to achieve a reputation and gain legitimacy despite scarce resources (Brem et al., 2017; Gimenez-Fernandez et al., 2020; Zhang et al., 2021). Yet little is known about openness in start-ups (Eftekhari and Bogers, 2015; Gimenez-Fernandez et al., 2019, 2020) or how open strategies change over time (Appleyard and Chesbrough, 2017). This is partly because of differences in open innovation (OI) between larger and smaller companies (Brunswicker and Vanhaverbeke, 2015; Vanhaverbeke, 2017; Greul et al., 2018; Bertello et al., 2022). Additionally, it is unclear what role, if any, appropriability mechanisms (particularly formal ones) play in the performance of start-ups, especially the open ones: while some studies have signalled that small, young firms require appropriability mechanisms in combination with openness in order to be successful (Holgersson, 2013; Brem et al., 2017), other studies point out that openness might also expose small firms to certain risks of knowledge leakage (Katila et al., 2008; Alberti and Pizzurno, 2017; Stefan et al., 2021). Furthermore, high costs and lengthy duration of enforcing appropriability mechanisms (Brem et al., 2017) hinder small, young firms from securing formal appropriability (FA).

Some prior studies suggest nevertheless that despite high costs (Gredel et al., 2012; Brem et al., 2017) formal appropriability mechanisms (FAMs), particularly patents are crucial for small young firms, both for attracting investors (Heger and Hussinger, 2017; Zhang et al., 2019) and for innovation collaboration (Andries and Faems, 2013). This remains yet another dilemma in the case of young firms, i.e., on one hand, lacking resources to enforce FA (Graham and Sichelman, 2008; Bulthuis, 2020); on the other hand needing FAMs in order to attract funding or innovation partners (Mann and Sager, 2007; Greenberg, 2013).

To our knowledge, how start-ups combine openness and FA remains unanswered, in particular related to the innovation activities. Such challenges may be linked to the paradox of openness, highlighting tensions between value creation and appropriation in OI, but this debate has been carried out mainly in large firms (Laursen and Salter, 2014; Foege et al., 2019; Ritala and Stefan, 2021) or without distinguishing between firm size (Grimaldi et al., 2021). Even though paradoxical tensions may occur between openness and appropriability in start-ups, its study might be more prominent at earlier stages when mechanisms such as reputation or bargaining power are not yet in a start-up's portfolio (Greenberg, 2013). Therefore, tensions as well as synergies between openness and appropriability require further attention. Scholars call for further research to deepen on this topic (Zobel et al., 2016; Stefan and Bengtsson, 2017), especially considering the particularities of start-ups (Eftekhari and Bogers, 2015; Greul et al., 2018). In this paper, we consider openness and FA strategies as endogenous variables at firm level that firms can use to enhance their innovation performance, contributing to the understanding of openness-appropriability equilibrium.

This study's aim is twofold: (1) to uncover how and if start-ups enforce FA and openness over time and how these choices might change during different stages of firm growth; and (2) to investigate the effect of openness and FA choices on start-ups' innovation performance, analysing some particularities of start-ups, such as the stage of development and their intensity of R&D. The analysis of these two factors is worthy given that contingent factors that might influence the tensions between openness and appropriation (Laursen and Salter, 2014; Niesten and Stefan, 2019; Yacoub et al., 2020; Zobel et al., 2016). In particular, at the early stages or for high-R&D intensive start-ups, there is a stringent need to access partners' resources at the same time that they protect their innovations and signalise their quality, as it will be explained in the Hypotheses development section. To test our hypotheses we use a representative sample of Spanish start-ups from the Spanish Technological Innovation Panel (PITEC), collected by the Spanish National Statistics Institute (INE). Our results show that start-ups tend to change their openness and FA strategies over time, yet that they benefit from the synergies of openness and FA, which together enhance innovation performance to a larger extent than if considered individually.

The findings have relevant theoretical and managerial implications. Namely, we contribute to OI literature by investigating openness-FA patterns over time and delineating strategic choices of start-ups at different stages of their growth. We further contribute to entrepreneurship literature by highlighting the importance of combining openness and formal protection in earlier start-up stages, which could inform entrepreneurs of their needs and focus at such stages, but also on the dynamics shifts at later start-up phases.

2. Conceptual background and hypotheses

2.1. Openness and appropriability in start-ups

According to Schumpeter (1934) start-ups are a source of creative destruction, yet research also

emphasises the benefits for start-ups from opening up to external partners in innovation (Colombo et al., 2006; Eftekhari and Bogers, 2015; Aggarwal and Wu, 2019). Openness has broadly been defined as knowledge flowing over organisational boundaries, using pecuniary and/or non-pecuniary mechanisms (Chesbrough and Bogers, 2014). Knowledge sharing or exchange across organisational boundaries, which enables value creation, is often regarded as a type of collaborative activity in innovation (Bogers, 2011). Therefore, in our study we refer to openness as cooperation. Benefits that start-ups might source from external actors include overcoming their smallness and newness liabilities by gaining access to human and economic resources (Neyens et al., 2010; Moghaddam et al., 2016; Corvello et al., 2017; Ferreira et al., 2019; Kraus et al., 2020), or developing complementary assets (Teece, 1986; Aggarwal and Wu, 2019). From an organisational learning perspective, start-ups can learn from their partners and become more proficient at managing external relationships (Fuerst and Zettinig, 2015) since organisational learning produces new organisational routines (Sapienza et al., 2006). Moreover, the theory of "learning advantages of newness" proposed by Autio et al. (2000) suggests that start-ups have some advantages, such as organic structures that allow quick transmission and assimilation of external knowledge. According to the theory of knowledge spillover entrepreneurship, start-ups act as a conduit of external ideas and knowledge, grasping external entrepreneurial opportunities that are left uncommercialized by established firms because of their uncertainty (Audretsch and Keilbach, 2007). The diverse knowledge provided by external sources gives start-ups new knowledge insights that foster the identification of business opportunities, supporting exploration innovation (March, 1991). Cooperation activities have tended to be related to exploration activities since they are described as opportunity-seeking (Sirén et al., 2012) as they look for creating knowledge and enhancing the innovation outcome through external search strategies (Radicic and Pugh, 2017). While these potential benefits for start-ups collaborating with external actors have been documented, openness in start-ups has been scarcely explored more in-depth (Usman and Vanhaverbeke, 2017). For instance, little is known about how openness shifts over time (Granstrand and Holgersson, 2014; Appleyard and Chesbrough, 2017; Holgersson et al., forthcoming) and since start-ups experience more turbulence in their development period compared to more established firms, it is particularly of interest how openness dynamics shifts over time in start-ups. We use the term openness dynamics here, i.e., moving from closed to open, or from open to closed innovation approaches (Markovic et al., 2021). Furthermore, while the resource scarcity of small young firms often requires openness to collaborate, such firms are also more exposed to unintended knowledge leakage (Katila et al., 2008; Alberti and Pizzurno, 2017; Mattioli and Lombardo, 2020), often because of asymmetries with their partners (Rothaermel and Deeds, 2004; Corvello et al., 2021) or because of lack of experience and lack of market and intellectual property (IP) knowledge (Gans and Stern, 2003; Moghaddam et al., 2016; Niesten and Stefan, 2019). Such risks are often conceptualised as the paradox of openness, i.e., balancing knowledge sharing and protection in OI (Laursen and Salter, 2014; Arora et al., 2016; Yacoub et al., 2020). The paradox of openness has been illustrated in some studies through the juxtaposition of openness and appropriability (see, e.g., Laursen and Salter, 2014; Stefan and Bengtsson, 2017; Yacoub et al., 2020). However, more recent studies point to finer delineation between appropriability and appropriation and also highlight the fact that openness and appropriability are not necessarily always in tension (Hurmelinna-Laukkanen and Yang, 2022). In line with this, some scholars have pointed out that start-ups' openness choices ought to be complemented with suitable appropriability strategies (Holgersson, 2013; Brem et al., 2017).

Young firms are highly innovative, being responsible to a higher degree for the introduction of radical innovations (Haltiwanger et al., 2013; Veugelers and Schneider, 2017). Additionally, small young firms need FAMs to signal the value of their IP to external actors (Greenberg, 2013). Therefore, we argue that FAMs play a more critical role for start-ups compared to established firms. Consequently, in this study we focus specifically on the importance of combining (or not) FAMs and openness in start-ups, in line with the study by Brem et al. (2017). There are four main FAMs: patents, trademark, copyrights and design rights (Hall et al., 2014). Hurmelinna-Laukkanen and Yang (2022) find that a large portion of the analysed studies (roughly 40%) regarded FAMs to be central to organisational appropriability strategies, with patents being the mechanism in focus. FAMs are often used as an isolating and defensive mechanism to ensure that what a firm wants to be kept away from others is also possible (Lippman and Rumelt, 2003) and the value that entrepreneurs can appropriate from their innovation activities (Foss and Foss, 2008). FAMs provide a legal protection against rivals and prevent imitation, giving the company ownership rights, leveraging strategy, building a reputation with customers and other stakeholders,

and facilitating external relationships (Mazzoleni and Nelson, 1998; Hall and Ziedonis, 2001; Vries et al., 2017). Criscuolo et al. (2012) argued that the development of appropriability mechanisms to capture the rents from innovations is critical for start-ups since incumbent firms are usually in control of the complementary assets. We note here that other studies suggest young innovative ventures might benefit more from employing informal appropriability (Anton and Yao, 2004), yet scholars have also pointed out that start-ups that do resort to appropriability mechanisms more often combine formal and informal ones (Thomä and Bizer, 2013).

As previously mentioned, FAMs are themselves a quality stamp of firms' technology (Gick, 2008). This signalling function reduces information asymmetries and is especially relevant for start-ups, which are not well-known in the market yet because of their newness, allowing them access to finance (Conti et al., 2013) and to signal quality to attract collaboration partners or investors (Holgersson, 2013). FA diminishes risks of partners' opportunistic behaviour (Teece, 2000; Laursen and Salter, 2014) since FAMs are enforceable in legal suits. It is crucial for start-ups since they are over-dependent on their partners. Nevertheless, FAMs are costly to enforce, start-ups often lack the resources and knowledge to enforce FA (Holgersson, 2013; Brem et al., 2017), and they might be less aware about IP and contracts (Stefan et al., 2021). Such questions of enforcing or not appropriability mechanisms also raise issues of appropriability dynamics, i.e., the varying availability and strength of appropriability, as well as tailoring these to opportunities or hazards (Hurmelinna-Laukkanen and Puumalainen, 2007). There is additionally a lack of consensus as to whether or not FA is beneficial when combined with openness in start-ups (Brem et al., 2017).

Taking into account tensions and complementarities between openness and FA, we propose a matrix, which consists of four categories (see Figure 1): (1) Open-Protective referred to start-ups that are open and have a FA mechanism, (2) Open-Non-protective, for start-ups with an open strategy, but without FAMs, (3) Closed-Protective, referred to start-ups with a closed innovation strategy, but with FAMs, and (4) Closed-Non-protective, which includes start-ups with a closed innovation strategy, and without FAMs. We label start-ups that use FA as Protective and the ones that do not as Non-protective because previous studies have shown that young firms using FAMs also enforce informal ones, while the young firms that do not use FA often do not use any type of IP protection mechanism (Thomä and Bizer, 2013). This matrix will be used to test our hypothesis.

2.2. *The effects of openness and formal appropriability on start-ups' innovation performance*

As shown in the previous section, both openness and appropriability may have numerous benefits on innovation performance; however, less is known about the combination of the two. The interplay between openness and appropriability has received some attention in entrepreneurship and OI literature. For example, Katila et al. (2008) argued that entrepreneurs take the risk of collaboration when they need resources that established firms uniquely provide, and when they have effective defence mechanisms to protect their own resources. Zobel et al. (2016) referred to a sample of new entrants, analysing how the patents stock influences the subsequent openness, and considering the contingency of the technology intensity of the relationship. However, the joint effects of openness and FA on start-ups' innovation performance are more scarce, having been the focus of a single strategy. In this sense, recent studies suggest that openness (in particular breadth, but also marginally depth) positively affects start-ups' innovative performance because it helps to generate sales from the commercialization of their new products (Hahn et al., 2019). In the same way, research has analysed the effects of FA on innovation performance (Veugelers and Schneider, 2017). FAMs can also be used to attract partners with complementary assets (Teece, 1986; Colombo et al., 2006; Wang et al., 2015), so start-ups will use them as a signal of quality to build cooperation relationships, enhancing their exploration innovation, as well as to attract investors (Holgersson, 2013; Heger and Hussinger, 2017; Zhang et al., 2019). Furthermore, start-ups can leverage their partners reputation to help their performance (Moghaddam et al., 2016)

		Formal appropriability strategy	
		Protective	Non-protective
Openness strategy	Open	(1) Open-Protective	(2) Open-Non-protective
	Closed	(3) Closed-Protective	(4) Closed-Non-protective

Figure 1. Matrix openness and formal appropriability strategies.

by endorsing public confidence about the value of the start-up and its products (Stuart, 2000), or exploiting their channels (Ketchen et al., 2007), so partners provide start-ups with market access and commercial linkages, which would benefit start-ups innovation performance given that they tend to lack the knowledge necessary to successfully commercialise new products and services (Colombo et al., 2006). Otherwise, start-ups would be disadvantaged in capturing the returns to innovation until they get access to downstream complementary assets (Criscuolo et al., 2012).

Recent studies point to the importance of balancing openness and protectiveness, i.e., an overfocus on either appropriability mechanisms or on opening up and sharing knowledge would be detrimental for firms (Niesten and Stefan, 2019). Indeed, Brem et al. (2017) found that although OI has a positive impact on firm performance in SMEs, this impact only occurs when coupled with suitable IP rights. In a similar vein, Criscuolo et al. (2012) found that start-ups with a strong use of legal appropriability methods are able to achieve higher returns for their product innovations than established firms due to the importance of strong appropriability regimes. Therefore, focusing on a combination of openness and protective strategy will let start-ups pursue their innovation performance.

All in all, we propose that the combination of openness and FAMs will enhance start-ups' innovation performance.

Hypothesis 1 The combination of openness and FAMs has a positive effect on innovation performance.

2.3. *The effects of openness and formal appropriability on start-ups' innovation performance according to their stage of development*

Literature on OI argues for different contingent factors that might influence tensions between openness and appropriation (Thomä and Bizer, 2013; Laursen and Salter, 2014; Zobel et al., 2016; Niesten and Stefan, 2019; Yacoub et al., 2020). However, research in this area is still limited for start-ups, and given the particularities of start-ups related to larger and older firms related to openness and FA strategies as seen in the conceptual background, it is important to analyse the relationship between the combination of openness and FAMs and the innovation considering the start-ups particularities, such as their stage of the development, and their level of R&D intensity.

Start-ups are a type of company that is continuously evolving and adapting to the changes in the environment (Vanhaverbeke, 2017). As a consequence, start-ups are dynamic, shifting their openness and FA strategies. For example, granted patents were found to positively impact start-up valuations especially in early stages (pre-revenue and early financing rounds), while at later stages of venture growth this impact diminishes (Greenberg, 2013). The explanation for this fact is that FAMs are more important to firms that lack other mechanisms to prevent the expropriation of their ideas, such as reputation, bargaining power, or network effects, and these mechanisms become more available to firms as they mature and establish proven track records (Greenberg, 2013). Some studies also suggest that start-ups might prefer other FAMs such as trademarks to patents (Brem et al., 2017) although patents seem to be preferred in earlier stages, when start-ups want to enter into markets with a high concentration and high market power of incumbents because patents perform as a stronger exclusion right than trademarks (Vries et al., 2017). Moreover, we expect that young firms would focus more on FAMs during the mid-early phase (up to five years) than during the consolidation phase (five to ten years) – following the phase typology suggested by Michelino et al. (2017) – regardless of the degree of openness because formal protection enhances information disclosure, and reduces asymmetries of information and adverse selection in the market for entrepreneurial finance (Arrow, 1962; Greenberg, 2013), and it is specially import to survive and avoid initial failure.

Studies on OI in start-ups point out that while openness is increasingly becoming an imperative for small young firms, its success is conditioned by the adjacency of FAMs (Holgersson, 2013; Thomä and Bizer, 2013; Brem et al., 2017).

Regarding openness dynamics (Granstrand and Holgersson, 2014; Appleyard and Chesbrough, 2017), previous studies find that the degree of openness for young firms is higher in mid-earlier, than in so-called consolidation phases because start-ups need to have access as early as possible to partners resources, such as cash flow, endorsement, innovative capabilities, and stable exchange relationships (Michelino et al., 2017). Furthermore, during earlier stages, external resources help start-ups to develop and market new products and avoid any risk associated with missteps in new product development and the potential for firm failure (Marion et al., 2012).

Young firms that do not focus on appropriability mechanisms have decreased levels of innovation

activities as compared to similar firms that employ appropriability – be it formal or informal – because those firms are less concerned with levels of innovativeness and return of innovation rents (Thomä and Bizer, 2013). The same authors further indicate that small firms do not use alternatively formal and informal appropriability strategies, but rather switch from protective to non-protective approaches altogether (Thomä and Bizer, 2013). As a result, the impact of a combinative strategy of openness and FA could differ over the start-up development, and we expect that the synergies of a combination of openness and FA to enhance innovation performance to be stronger during the earlier stages of a start-up.

Hypothesis 2 The combination of openness and FAMs has a stronger positive effect on innovation performance during the earlier stages of a start-up than in the consolidation stage.

2.4. *The effects of openness and formal appropriability on start-ups' innovation performance according to their level of R&D intensity*

OI literature argues that firms should combine internal and external knowledge (Chesbrough, 2006). However, literature has evidenced that small firms tend to restrict their innovation strategy to an exclusive internalise or externalise strategy (Veugelers and Cassiman, 1999), becoming negative for their innovation process. OI is more attractive for R&D-intensive firms (Alexy et al., 2016) as firms need an extensive knowledge base to absorb external knowledge (Cohen and Levinthal, 1990). Internal R&D therefore spurs OI (Alexy et al., 2016), building an entrepreneurial absorptive capacity to integrate external knowledge (Qian and Acs, 2013). Start-ups tend to be entrepreneurially oriented and open to disruptive technologies and opportunities (Christensen and Overdorf, 2000), so when start-ups are intensive in R&D investment and they have an open strategy, they have an explorative behaviour by searching, discovering and taking risks, which is also expected to support the process of commercialising innovations (Chiang and Hung, 2010; Hahn et al., 2019). Indeed, Veugelers and Schneider (2017) found that young companies with a high R&D intensive profile are more likely to use intellectual property mechanisms to appropriate the returns from their innovations. Under those circumstances, having FAMs would help them not only to protect their innovations, which would guarantee the capture of their innovation rents (Thomä and Bizer, 2013), but also to signalise their quality. As a consequence, the combination of openness and FA comes especially relevant for high R&D intensive start-ups' innovation performance.

Hypothesis 3 For R&D-intensive start-ups, the combination of openness and FAMs will have a greater impact on start-ups' innovation performance than it does for non-R&D-intensive start-ups.

3. Methodology

3.1. *Sample*

We test our model on a representative sample of innovative Spanish start-ups from the database Spanish Technological Innovation Panel (PITEC), collected by the Spanish National Statistics Institute (INE), in collaboration with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). The database has a wide sector coverage including manufacturing and service sectors[1], being representative of the population of Spanish firms. The survey is based on the core Eurostat Community Innovation Survey (CIS). CIS data has previously been used in the context of start-ups (Criscuolo et al., 2012; Colombelli et al., 2016; Gimenez-Fernandez et al., 2020). The advantage of PITEC related to CIS is that it gets longitudinal data from firms. Although PITEC was created in 2003, its questionnaire suffered important modifications from 2003 to 2004, where the biggest sample of start-ups was added, so our focal year is 2004. The present article therefore uses data from 2004 to 2013. We chose this ten-year period in order to control for firm survival and considering the start-up stages delineated by Michelino et al. (2017).

In the survey, firms are asked if they are start-ups – if the firm is a new creation or it was during the two last years – so we use this question to identify our sample. Accordingly, we select our sample of start-up firms by picking the firms that positively answered that question in 2004 (start-ups represent 4.72% of the full living sample). Further, we do not include firms that had more than 250 employees in 2004. The cut-off of 250 employees is based on the definition of an SME by the European Commission and the OECD (2005), and it has been used in other studies (Gimenez-Fernandez et al., 2020). A total of 339 firms confirmed being start-ups in the 2004 survey. These firms were then tracked annually through to the final (tenth) year, 2013. Table 1 provides information on the number of observations per year. The respondent numbers change year-by-year due to attrition, refusals, change of contact and business exits

Table 1. Sample and independent variable information per year

Year	Open-protective	Open-non-protective	Closed-protective	Closed-non-protective	Total
2004	99	51	71	110	331
2005	90	59	61	78	288
2006	85	60	52	79	276
2007	64	68	42	86	260
2008	52	70	33	82	237
2009	51	65	24	78	218
2010	40	65	19	73	197
2011	34	62	19	59	174
2012	32	50	17	58	157
2013	27	47	13	53	140
Total	574	597	351	756	2,278

and also due to some missing data, generating an unbalanced panel data. The unbalanced panel avoids the sample selection bias (Del Sarto et al., 2021) and provides a richer dataset to analyse the behavioural patterns related to openness and FA decisions.

3.2. Measures

3.2.1. Dependent variable

Although there are different typologies for technological innovation, we use revenue from product innovation as a proxy to indicate the innovative performance by firms as it has been traditionally used in the innovation literature (Faems et al., 2005, 2010; Nieto and Santamaría, 2007; Spithoven et al., 2013), and also applied in the context of start-ups (Criscuolo et al., 2012; Gimenez-Fernandez et al., 2020; Sedita et al., 2019). We measure product innovation performance as a proportion relative to the turnover of new or strongly improved products that the company introduced to the market and that were new to the market or to the firm during the last three years. New products to the market or to the firm are mutually exclusive since they add up to 100%, so innovation performance ranges from 0 to 100.

3.2.2. Independent variables

Our study analyses the impact of different strategies based on the combination of openness and FA strategies on start-ups innovation performance. To measure openness, we focus on cooperation relationships (Teirlinck and Spithoven, 2008). The questionnaire asks firms whether they cooperated or not with other firms or entities for technological innovation. In the same way, to measure the existence of FAMs, firms are asked whether they applied for four FAMs during the last three years: patents, trademarks, copyright, and design rights[2]. We use these questions to assess whether the firm has a FA strategy. Note that the parameter for FAMs refers to any of the four types of FAMs, avoiding the bias for patent preference, since some prior research suggests that start-ups might focus more on other FAMs such as trademarks (Vries et al., 2017; Brem et al., 2017) or designs (Power and Reid, 2023). To test the impact of the combination strategy of openness and FA, we combine the previous variables to create a double entry matrix defined by these two parameters – openness and FA – (see Figure 1): (1) Open-Protective, (2) Open-Non-protective, (3) Closed-Protective, and (4) Closed-Non-protective. The latter category is used as the benchmark.

In order to analyse the particularities of start-ups, we have proposed a series of hypotheses that consider some contingent factors. First, we argued that the impact of openness-FA might change along start-ups development. Following the phase typology suggested by Michelino et al. (2017), we distinguish between the early stage (up to five years), and the consolidation stage (five to ten years). Hence, we have created a binary variable that is 1 if observations are related to 2004–2008, and 0 otherwise; and we split the sample according to this variable (Lakemond et al., 2016). Second, we posited whether the impact of the analysed strategies is stronger for start-ups that have more internal R&D intensity. Hence, we have created a dummy variable to split our sample according to the internal R&D intensity level. This variable was calculated through the average internal R&D level of our sample, splitting the sample into start-ups with low R&D intensity if their R&D level was lower than the average; and start-ups with high R&D intensity if their R&D level was higher than the average.

3.2.3. Control variables

In order to rule out possible alternative explanations to those formally hypothesised, the model includes

the following control variables. First, scholars consider internal R&D to be crucial for innovation (Cohen and Levinthal, 1990), we include firms' internal R&D efforts measured as the proportion of its internal innovation expenses. Second, following prior literature we control for firm size, it is measured using the logarithm of the total number of employees (Colombelli et al., 2016). The logarithm transformation was made because there are large differences between firms and this variable might be skewed. Third, we include a dummy variable to control if the firm belongs to a group because firms belonging to a corporate group could bring knowledge from the large corporation influencing their innovation activities (Criscuolo et al., 2012). Fourth, another variable that could influence start-ups' innovation activities is the scope of the market where the firm sells its products. We control this, by controlling for the start-ups' involvement in different markets: local, national, European, and other international markets (Laursen and Salter, 2014). Fifth, start-ups operating in high-tech sectors could have a higher innovation performance (Luker and Lyons, 1997), so we include a dummy variable to indicate whether the firm operates in a high-tech industry. Finally, we also apply dummy variables to control the possible bias of the observation year. The year 2004 is used as a benchmark. A summary of the variables description can be found in Table A3.

4. Statistical method and results

Table 2 reports the annual descriptive statistics of the variables used in the analysis. Note that most of the start-ups (33%) have chosen the Closed-Non-protective strategy. This figure is followed by the Open-Non-protective strategy, then the Open-Protective strategy, and finally, the Closed-Protective strategy. As previously outlined, a potential reason for the general rejection to apply for FAMs might be its cost.

To better understand the dynamics of the openness-FA strategic choices of the companies, we have built a series of Figures (Figures 2–4) where we draw the path changes of the strategies, considering the phase typology suggested by Michelino et al. (2017), and distinguish between the early phase (up to five years), and the consolidation phase (five to ten years) (see also Table A4). In the early stage, the Open-Protective strategy is the most frequent, followed by the Closed-Non-protective, the Closed-Protective, and finally the Open-Non-protective strategy (see Figure 2). However, these choices change over time, and the Closed-Non-protective strategy increases at the consolidation stage; while the Open-Protective strategy becomes the third option at the following stages. It seems that the non-protective strategies become more relevant with firms' growth. We interpret this finding as a sign of a stringent need to be both open and to employ FA at earlier start-up stages (see the discussion section for further explanation).

Nevertheless, it is interesting to draw our attention to the subsample composed by the balanced panel data, which would include companies that report the whole ten-years period of analysis (see Figure 3 and Table A5). Again, if we distinguish by time periods, the most applied strategy for these firms is the Open-Protective strategy at earlier stages, and although this strategy keeps a substantial proportion of companies after some years, this figure starts to decrease, while the Open-Non-protective strategy increases. Nevertheless, a high number of firms do not change their openness-appropriability strategy during the consolidation stage, maintaining the Open-Protective strategy. Another group of companies tend to maintain the Open-Non-protective strategy. This preliminary analysis is in line with our argument that start-ups will benefit from an OI strategy and, in particular, with an Open-Protective strategy, especially during the earlier stages.

On the contrary, if we focus on the rest of firms, we observe that the pattern of the vast majority of them is towards the Closed-Non-protective strategy at the consolidation stage (see Figure 4). What is more, some of those that had chosen a protective strategy seem to not have survived as businesses.

Correlation coefficients of the variables used in the estimations are reported in Table 3. It is interesting to notice that the Open-Protective strategy is positively correlated to innovation performance, while the Closed-Non-protective strategy is negatively correlated to innovation performance. The Open-Non-protective strategy is not significatively correlated to innovation performance. None of the correlations are sufficiently strong to suggest multicollinearity problems. In addition, we conducted variance inflation factor (VIF) tests, and all the VIFs were lower than 1.5, suggesting that multicollinearity is not a problem in our results.

Following the approach of similar research analysing innovation (Laursen and Salter, 2006), we considered a censored Tobit model to deal with the large number of observations censored to the left. However, the assumption of normality of residuals in our model is not satisfied. To address this problem, Laursen and Salter (2006) assumed a lognormal

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Innovation performance	2,278	43.768	42.382	0	100
Open-Protective	2,278	0.252	0.434	0	1
Open-Non-protective	2,278	0.262	0.440	0	1
Closed-Protective	2,278	0.154	0.361	0	1
Closed-Non-protective	2,278	0.332	0.471	0	1
Internal R&D	2,278	64.196	38.564	0	100
Size	2,278	25.488	36.137	1	247
Group	2,278	0.297	0.457	0	1
Scope	2,278	2.456	1.064	1	4
High-tech	2,278	0.544	0.498	0	1

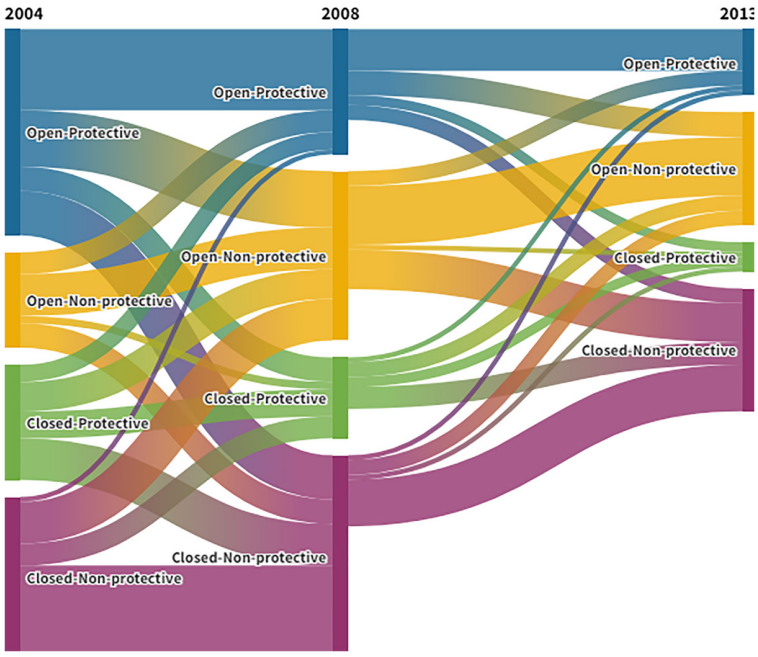

Figure 2. Evolution of openness-appropriability strategies. Full sample.

distribution for the residuals of the Tobit model. We also apply this approach and we introduce a latent variable for innovation performance as its logarithmic transformation. To control for unobserved heterogeneity (for example, time-invariant unobserved factors of innovation performance) that are not possible with a cross-section analysis (Lavie, 2007), we set panel data to estimate our regressions.

$$Ln(1+Innovation\ Performance)=\beta_0+\beta_1 Open-Protective+\beta_2 Open-Non-protective+\beta_3 Closed-Protective+\beta_4 InternalR\&D+\beta_5 Log(Size)+\beta_6 Group+\beta_7 Scope+\beta_8 High-Tech+\beta_9 Years+\varepsilon \quad (1)$$

The results of the Tobit regressions can be found in Table 4. First, we estimated Model 1, which contains the control variables. Then, Model 2 includes the variables related to the different categories of our matrix openness-appropriability compared to the category of Closed-Non-protective, using the full sample to test Hypothesis 1. Models 3–6 are tested in different subsamples to analyse the impact of openness-appropriability in different scenarios. In particular, Models 3 and 4 test the impact of openness-appropriability strategies on innovation performance in the different stages

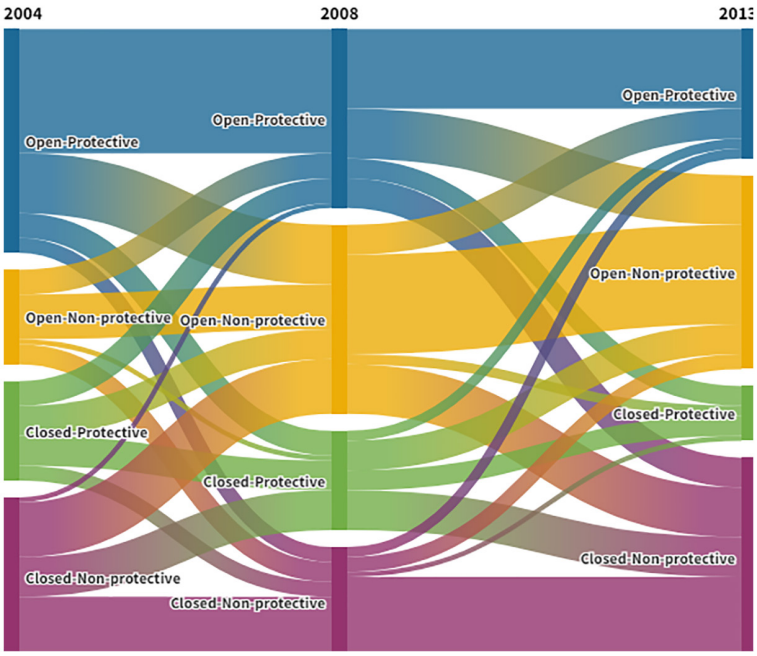

Figure 3. Evolution of openness-appropriability strategies. Balanced subsample.

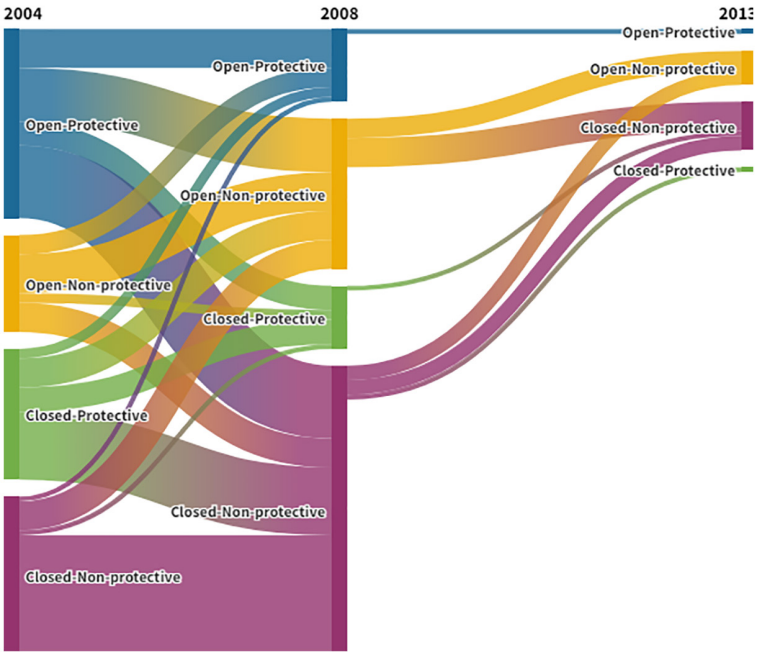

Figure 4. Evolution of openness-appropriability strategies. Unbalanced subsample.

of start-ups development (Hypothesis 2), distinguishing between the early stage, and the consolidation stage, respectively. These Models are tested in the balanced subsample to avoid any bias by attrition. Then, Models 5 and 6 analyse the impact of openness-appropriability strategies on innovation performance for non-intensive R&D start-ups, and for intensive R&D start-ups, respectively (Tables A4 and A5).

We hypothesised that the combination of openness and FAMs will have a positive impact on innovation performance. The estimations of Model 2 show that all the coefficients of the matrix are significant and positive, meaning that start-ups that either have an Open-Protective (β = 1.373; P<.001), Open-Non-protective (β = 1.068; P<.001), or Closed-Protective (β = 0.830; P<.001) strategy will outperform the start-ups with a Closed-Non-protective strategy. If we

Table 3. Correlation coefficients

	Inn. Perfor.	Open-Prot.	Open-Nonpr.	Closed-Prot.	Closed-Nonpr.	Internal R&D	Size	Group	Scope
Open-Protect.	0.162								
	.000								
Open-Non-pr.	−0.031	−0.346							
	.141	*.000*							
Closed-Protect.	0.056	−0.248	−0.254						
	.008	*.000*	*.000*						
Closed-Non-pr.	−0.163	−0.409	−0.420	−0.301					
	.000	*.000*	*.000*	*.000*					
Internal R&D	0.076	0.134	0.110	0.022	−0.243				
	.000	*.000*	*.000*	*.301*	*.000*				
Size	0.000	0.020	−0.014	−0.041	0.027	0.027			
	.988	*.347*	*.492*	*.049*	*.199*	*.197*			
Group	0.052	0.097	−0.016	−0.107	0.008	0.008	0.363		
	.013	*.000*	*.455*	*.000*	*.722*	*.706*	*.000*		
Scope	−0.008	0.102	−0.039	0.017	−0.071	0.076	0.240	0.089	
	.240	*.000*	*.064*	*.416*	*.001*	*.000*	*.000*	*.000*	
High-tech	0.079	0.174	0.072	−0.015	−0.216	0.259	−0.118	−0.048	−0.142
	−.118	*.000*	*.001*	*.480*	*.000*	*.000*	*.000*	*.022*	*.000*

P-value in italics.

Table 4. Tobit panel regression

	Control	Full	Early stage	Consol. Stag.	Low R&D	High R&D
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Internal R&D	0.002	0.000	–0.004	0.005	0.012***	–0.017***
	[0.002]	[0.002]	[0.004]	[0.003]	[0.004]	[0.006]
Size	0.235***	0.217***	0.082	0.457***	0.073	0.197**
	[0.068]	[0.066]	[0.132]	[0.156]	[0.097]	[0.086]
Group	0.203	0.175	0.172	0.268	0.101	0.274
	[0.166]	[0.163]	[0.299]	[0.321]	[0.257]	[0.199]
Scope	0.218***	0.177***	0.131	–0.165	0.337***	0.06
	[0.066]	[0.065]	[0.110]	[0.116]	[0.107]	[0.078]
High-tech	0.131	–0.019	0.234	–0.091	0.018	–0.098
	[0.143]	[0.140]	[0.279]	[0.312]	[0.223]	[0.168]
Year	Yes	Yes	No	Yes	Yes	Yes
Open-Protec.		1.373***	1.757***	0.989***	1.194***	1.386***
		[0.157]	[0.276]	[0.302]	[0.286]	[0.192]
Open-Non-prot.		1.068***	1.578***	0.558**	0.666**	1.114***
		[0.148]	[0.279]	[0.253]	[0.260]	[0.182]
Closed-Protec.		0.830***	1.128***	1.207***	0.567**	1.029***
		[0.165]	[0.306]	[0.358]	[0.269]	[0.210]
Constant	1.782***	1.376***	1.182**	0.732	1.676***	3.061***
	[0.253]	[0.253]	[0.535]	[0.589]	[0.391]	[0.644]
sigma_u	1.336***	1.291***	1.155***	1.671***	1.420***	1.361***
	[0.080]	[0.079]	[0.124]	[0.155]	[0.131]	[0.096]
sigma_e	2.065***	2.028***	1.784***	1.533***	2.064***	1.896***
	[0.041]	[0.040]	[0.068]	[0.061]	[0.075]	[0.047]
Log Likeli~d	–4,319.236	–4,275.458	–1,105.176	–1,018.1	–1,548.997	–2,707.425
No of Obs	2,278	2,278	580	580	838	1,440
No of left c ~ s	611	611	116	145	256	355
rho	0.2949525	0.2883536	0.2954556	0.5429828	0.321377	0.3402797
Wald-Chi2	160.5656***	249.9255***	54.0188***	67.13443***	144.9991***	141.9713***

Standards errors in brackets.
*$P<.10$, **$P<.05$, ***$P<.01$.

attend to the value of those coefficients, we observe that the coefficient for the Open-Protective strategy is higher than the coefficients for the rest of categories, suggesting for the positive impact of a combination of both strategies on start-ups' innovation performance, and supporting Hypothesis 1. To test whether the difference between the coefficients of the different strategies is significant, we additionally ran a Wald test (see Table 5). In particular, we compared the coefficient for the Open-Protective strategy to the Open-Non-protective strategy (Chi2 = 87.38; $P<.001$), and to the Closed-Protective strategy (Chi2 = 78.45; $P<.001$). All the tests resulted in significant, supporting Hypothesis 1. Additionally, Milgrom and Roberts (1995) proposed that the synergistic effect between two factors happens when the total economic value added by combining those two factors in a production system exceeds the value that would be generated by applying those production factors in isolation. Following that methodology, we checked for the synergies between openness and FA, testing whether the effect of the Open-Protective strategy in start-ups' innovation performance is higher than the sum of the Open-Non-protective and Closed-Protective strategies. This test also resulted in significant (Chi2 = 6.13; $P<.05$), providing full support to Hypothesis 1.

To understand the heterogeneity of start-ups and how it might affect the choice in the openness-appropriability strategy, we conducted several regressions. First, we hypothesised that the combination of openness and FAMs has a stronger positive effect on innovation performance during the earlier stages of a start-up than in the consolidation stage. To test this hypothesis we followed the stage typology suggested by Michelino et al. (2017) and split our sample into two subsamples, one with the observations regarding the early-stage, so years 2004–2008 (first five years), and the other with the observations regarding the consolidation stage, so years 2009–2013 (last five years). Because we are comparing the two stages, and to avoid any bias caused by attrition, we conducted these regressions using the balanced subsample. The estimations of Models 3 and 4 (Table 4) show that all the coefficients of the matrix are significant and positive. However, when looking at the value of those coefficients, we observe that the coefficient for the Open-Protective in the early stage subsample is higher than the coefficients for the rest of categories ($\beta = 0.830$; $P<.001$), while in the consolidation stage, the coefficient for the Closed-Protective strategy is slightly higher than the others. It supports the positive impact of a combination of both strategies on start-ups' innovation performance during the early stage, hence supporting Hypothesis 2. Again, to test whether the difference between the coefficients of the different strategies is significant, we additionally ran a Wald test (see Table 5). It resulted that the coefficient for Open-Protective is higher than the rest of coefficients in the early stage, even higher than the sum of the Open-Non-protective and Closed-Protective strategies (Chi2 = 6.51; $P<.05$), providing full support for Hypothesis 2.

Second, we posit whether the impact of the Open-Protective strategy is stronger for start-ups that have more internal R&D intensity. From Table 4, Models 5 and 6, we again observe that the Open-Protective strategy is positive and significant ($\beta = 1.194$; $P<.001$), being this coefficient higher than in any other strategy, and being higher for high R&D intensive start-ups. Again, the Wald tests show that the coefficient for Open-Protective is higher than the rest and that there is a synergistic effect in the case of high R&D intensive start-ups (Chi2 = 6.13; $P<.05$). These results confirm our Hypothesis 3.

To test the robustness of our findings, we ran several additional regressions (see Appendix). First, we confirmed that the random Tobit panel regressions are robust to alternative estimations. We ran random effect OLS regressions (the Hausman test revealed that random effects are preferred to fixed effects),

Table 5. Wald tests

	OP>ONp	OP>CP	OP>(ONp+CP)	OP>ONp	OP>CP	OP>(ONp+CP)
	Model 2			Model 3		
Chi2	87.38	78.45	6.13	45.42	40.72	6.51
P-value	.000***	.000***	.013**	.000***	.000***	.011**
Free. Degr.	2	2	1	2	2	1
	Model 5			**Model 6**		
Chi2	18.21	17.83	0.01	87.38	78.45	6.13
P-value	.000***	.000***	.919	.000***	.000***	.013**
Free. Degr.	2	2	1	2	2	1

OP: Open-Protective; ONp: Open-Non-protective; CP:Closed-Protective.
*$P<.10$, **$P<.05$, ***$P<.01$.

Table 6. Summary of hypotheses testing results

Hypothesis	Description	Result	Discussion
H1	The combination of openness and FAMs has a positive effect on innovation performance	Supported	Opening to external partners and signalling the value of their IP, while also protecting IP through formal appropriability mechanisms is essential for start-ups, getting synergies to enhance innovation performance
H2	The combination of openness and FAMs has a stronger positive effect on innovation performance during the earlier stages of a start-up than in the consolidation stage	Supported	The needs of openness and appropriability mechanisms change over time, being stringently necessary at very early start-up stages because start-ups need to have access as early as possible to partners' resources and reduce asymmetries of information
H3	For R&D-intensive start-ups, the combination of openness and FAMs will have a greater impact on start-ups' innovation performance than it does for non-R&D-intensive start-ups	Supported	There is a synergistic effect between openness and formal appropriability in the case of high R&D intensive start-ups because they tend to be more open, explorative and innovative, taking risks, so they need FAMs to protect their innovations, capture the rents of their innovations, and signal their quality

and results are similar to those found in Table 3, supporting Hypotheses 1 to 3 (see Table A6). Second, not all the firms included in our sample survived to the whole period of analysis. Attrition may generate a bias of survivorship that may distort the estimates (Colombo et al., 2006). Hence, we tried to control for its extent by introducing a dummy variable that measures whether the firm survived to the next year or not (see Table A7). We found support for Hypotheses 1 and 3. To test the robustness of Hypothesis 2, we considered the full sample, and the strength of the coefficient is higher for the consolidation stage than for the early stage, but a synergy between openness and FA exists for the early stage, but not for the consolidation stage, suggesting some support for Hypothesis 2.

5. Discussion and theoretical contribution

Our study contributes to literature on: (1) the interplay of openness dynamics (Holgersson et al., forthcoming) and appropriability dynamics (Hurmelinna-Laukkanen and Yang, 2022), (2) the paradox of openness (Bogers, 2011; Laursen and Salter, 2014), and (3) bridging the literature on OI and entrepreneurship.

First, we contribute with new insights on the interplay between openness and appropriability, focusing more specifically on the dynamics of openness and FA and its impact on start-ups' innovation performance. We do this by building a matrix that links openness and FAMs and showing how choices of openness and FA fluctuate over time (see Figures 2–4), thereby shaping the four strategies. This indicates that start-ups' development of external relationships could be regarded as a strategic process that they manage proactively (Rindova et al., 2012). Furthermore, start-ups face the liabilities of smallness and newness (Gimenez-Fernandez et al., 2020), so opening to external partners and signalling the value of their IP through FA mechanisms becomes crucial (Greenberg, 2013; Ferreira et al., 2019; Kraus et al., 2020; Corvello et al., 2021). While at early start-up stages our findings confirm that both FA (for signalling reasons) and openness (for collaboration and investment reasons) are essential, these choices are subject to changes over time, highlighting an interplay between openness dynamics (Appleyard and Chesbrough, 2017; Markovic et al., 2021; Holgersson et al., forthcoming) and appropriability dynamics (Hurmelinna-Laukkanen and Puumalainen, 2007; Hurmelinna-Laukkanen and Yang, 2022). Thus, we suggest that the tensions between openness and FAMs should not be regarded as mutually exclusive, but they can be used in a synergistic manner (Ritala and Hurmelinna-Laukkanen, 2013; Holgersson et al., 2018; Lauritzen and Karafyllia, 2019; Hurmelinna-Laukkanen and Yang, 2022).

From the perspective of R&D intensity, the positive impact of combining openness and FA might also create a synergistic effect in the case of R&D intensive start-ups, providing a second contribution to theory on the "paradox of openness" (Bogers, 2011; Laursen and Salter, 2014) for start-ups. Building on the resource-based view (Cohen and Levinthal, 1990), high-intensive start-ups

tend to be more open (Alexy et al., 2016) and they become more explorative and build an entrepreneurial absorptive capacity to integrate external knowledge (Qian and Acs, 2013). At the same time, they need FAMs to protect their innovations (Brem et al., 2017), capture the rents of their innovations (Veugelers and Schneider, 2017) and signalise their quality (Greenberg, 2013), creating a synergistic effect of both strategies that enhance innovation performance.

While identifying synergies and combining openness and FAMs becomes a crux for enhancing innovation performance and overcoming their liability of newness (Gimenez-Fernandez et al., 2020), we also observe that not all start-ups succeed employing an Open-Protective strategy at early stages. This could further point to the tensions spurring from openness and appropriability competing for the same resources (Stefan and Bengtsson, 2017) and start-ups general lack of resources (Gredel et al., 2012; Brem et al., 2017). A possible takeaway here would be that while synergies between openness and FA may be highly beneficial for start-ups at early stages, (Greenberg, 2013; Michelino et al., 2017), they are also difficult to achieve given resource scarcity of new ventures.

Hence, a contribution also specific to the paradox of openness (Bogers, 2011; Laursen and Salter, 2014) would be that in early start-up stages when resources are scarce (Brem et al., 2017) and reputation, bargaining power or network effects are lacking (Greenberg, 2013) represent a point of highly salient tensions in the paradox of openness (if FAMs are required), since synergies between openness and FA render stronger effects on innovation performance. Based on our findings, it could further be suggested that the more established new ventures become, the tensions within the paradox of openness may decrease, seeing as towards the consolidated stages more firms tend to adopt less protective strategies in terms of FAMs.

Third, we contribute to the integration of streams of literature on OI (Jensen and Webster, 2009; Huang et al., 2014; Laursen and Salter, 2014; Arora et al., 2016; Miozzo et al., 2016) and entrepreneurship (Gans and Stern, 2003; Katila et al., 2008; Dushnitsky and Shaver, 2009; Hsu and Ziedonis, 2013), answering to the claim of OI scholars to focus on start-ups as differentiated from established firms and SME (Criscuolo et al., 2012; Usman and Vanhaverbeke, 2017), and the claim of entrepreneurship literature of considering innovative start-ups as a distinct form of entrepreneurship (Audretsch et al., 2020). In Table 6, there is a summary of the hypotheses and their discussion.

6. Conclusion

This study examines the dynamics of openness-FA and the impact of its combination on start-ups' innovation performance, as well as the effect of the stage of development and the intensity of R&D on this relationship, for a period of ten years. In this paper, we have considered openness and FA strategies as endogenous variables at the firm level that firms can use to enhance their innovation performance. Based on our findings, start-ups could choose between Open-Protective, Open-Non-protective, Closed-Protective, and Closed-Non-protective strategies, tailoring openness and FA depending on their need to be open or closed and also on their requirement to signal valuable IP with FAMs (or not). These strategies are dynamic and start-ups tend to move from one to another over their development. In particular, we have evidenced that the positive impact of the combination of openness and FA is higher for start-ups in their early stages, or if they are R&D intensive, creating a synergistic effect between both strategies.

6.1. Practical and policy implications

While literature has focused on start-ups as vehicles for creating new innovations (e.g., Schumpeter, 1934; Katila and Shane, 2005), we highlight that start-ups should also possess appropriability mechanisms in order to avoid knowledge leakages and signalling their qualities. Focusing on both – openness and FA – could be essential for start-ups pursuing innovation activities. Hence, we recommend start-up managers in industries where FA is relevant to allocate some resources to any appropriability mechanism, given the importance of this strategic choice for innovation performance, and considering the course of several distinct phases of their emergence and growth.

The conundrum between the need to combine openness and FA at earlier start-up stages and the challenges posed by expensive and lengthy enforcement of formal IP mechanisms also has implications for the IP policy – suggesting that perhaps small, young firms might benefit from lower fees to apply for FA – as well as for technological growth, seeing as start-ups are most often the originators of disruptive solutions.

6.2. Limitations and future research

Although this study reveals some interesting points, it has several limitations, which provide opportunities for future research. First, future research could consider more comprehensive measures of openness, appropriability and performance, while also considering the

role of ambidexterity (He and Wong, 2004; Rothaermel and Alexandre, 2008). For example, our research only considers FAMs since we do not have data available regarding informal appropriability mechanisms. Informal instruments can also be used in a complementary way to enhance the start-ups' innovation performance. However, our study also highlights the importance of using FA in start-ups, while many scholars have focused more on informal ones to the relatively lower use of IP rights by start-ups (see, e.g., Anton and Yao, 2004). Moreover, because we are using secondary data, we cannot control for the number of product innovations, and our dependent variable is measured in terms of percentage of turnover.

Second, our sample could suffer from some survivorship bias. As we conducted robustness tests and these support our findings we are not concerned about this. Third, another caveat related to the sample is the age of our dataset, however, given the definite dataset was created in 2004, the bigger sample of start-ups belongs to that cohort. Including additional waves of the questionnaire would distort the study of the start-up phenomenon. Fourth, even though we have considered several factors to control for heterogeneities between start-ups, there are other start-up and context characteristics that could be interesting to investigate in the future. For example, the relationship between openness and FA might be different for certain types of partners and appropriability mechanisms.

Fifth, given the costs that FA incurs (Brem et al., 2017) and the limited resources of start-ups (Eisenhardt and Schoonhoven, 1996; Ketchen et al., 2007; Neyens et al., 2010), future studies might also focus on the mechanisms and strategies that start-ups employ to resolve this resource dilemma successfully. Sixth, costs of closing OI (Holgersson et al., forthcoming) should also be further explored concerning start-ups. Finally, future research could also explore further the limits between appropriability and appropriation (Hurmelinna-Laukkanen and Yang, 2022), specifically on whether an enforced appropriability mechanism also constitutes a tool for value capture or is limited to the appropriability strategy of the firm.

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Ethics statement

Not applicable.

Data availability statement

Raw data were generated at the Spanish National Statistics Institute (INE), in collaboration with the Spanish Science and Technology Foundation (FECYT) and the Foundation for Technological Innovation (COTEC). Derived data supporting the findings of this study are available from the corresponding author on request.

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Notes

[1] See Table A1 in the Appendix for a more detailed view of the sample industry sectors.

[2] See Table A2 in the Appendix for a more detailed view of the frequency of each FA strategy.

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APPENDIX A

Table A1. Number of firms by sector in 2004

Sector	Frequency	Percentage
Agriculture, farming, forestry, and fishing	5	1.51
Extraction industry	2	0.6
Food and beverage	21	6.34
Textile	5	1.51
Wood and cork	1	0.3
Paper and cupboard	1	0.3
Graphic arts and reproduction	2	0.6
Chemistry	14	4.23
Pharmacy	6	1.81
Plastic and rubber	5	1.51
Non-metallic mineral products	3	0.91
Ferrous metallurgy	1	0.3
Metallic factories	8	2.42
Mechanic machinery and equipment	11	3.32
Electrical machinery and material	5	1.51
Electronic components	2	0.6
Radio, TV, and communication equipment	5	1.51
Medical equipment and optical products	14	4.23
Motor vehicles	4	1.21
Shipbuilding industry	1	0.3
Aeronautic and space building	1	0.3
Other transport equipment	2	0.6
Furniture	4	1.21
Other manufacturing activities	1	0.3
Recycling	3	0.91
Energy, gas, and water	3	0.91
Building	6	1.81
Sold and repair of motor vehicles	1	0.3
Wholesale	7	2.11
Retail	3	0.91
Hotel and catering business	3	0.91
Transport related activities and travel agency	1	0.3
Posting	1	0.3
Telecommunication services	7	2.11
Finance and brokering	2	0.6
Real estate activities	1	0.3
Software	41	12.39
Other computing activities	14	4.23
R&D	50	15.11
Architecture and engineering services	29	8.76
Trials and technical analysis	10	3.02
Other business activities	13	3.93
Movie and video activities	2	0.6
Radio and TV activities	1	0.3
Other health, social and collective activities	9	2.72
Total	331	100

Table A1. (Continued)

Table A2. Frequency of each formal appropriability mechanism

	Patents	Trademarks	Copyright	Design rights
2004	97	123	15	43
2005	78	107	14	36
2006	74	99	6	26
2007	63	68	4	22
2008	51	53	6	16
2009	54	51	3	10
2010	41	35	4	11
2011	36	31	3	11
2012	38	25	3	5
2013	29	16	2	6
Total	561	608	60	186

Table A3. Variable description

Variable	Description
Innovation performance	Proportion relative to turnover of new or strongly improved products that the company introduced to the market and that were new to the market or to the firm
Open-Protective	Dummy variable to indicate that the firm cooperated with other firms or entities for technological innovation, and applied for any of the following four FAMs during the last three years: patents, trademarks, copyright, and design rights
Open- Non-protective	Dummy variable to indicate that the firm cooperated with other firms or entities for technological innovation, but not applied for any of the following four FAMs during the last three years: patents, trademarks, copyright, and design rights
Closed-Protective	Dummy variable to indicate that the firm did not cooperated with other firms or entities for technological innovation, but applied for any of the following four FAMs during the last three years: patents, trademarks, copyright, and design rights
Closed- Non-protective	Dummy variable to indicate that the firm did not cooperated with other firms or entities for technological innovation, nor applied for any of the following four FAMs during the last three years: patents, trademarks, copyright, and design rights
Start-up development	Dummy variable to indicate whether the firm is in the mid-early phase (up to five years), or in the consolidation phase (five to ten years)
R&D intensity	Dummy variable to indicate whether the firm R&D level was higher than the average of the companies in the sample or not
R&D efforts	Proportion of internal R&D expenditure
Size	Natural logarithm of the total number of employees
Group	Dummy variable to indicate if the firm belongs to a firm group
Scope	Addition of the involvement in different markets: local, national, European, and other international markets
High-tech	Dummy variable to indicate whether the firm belongs to a high-tech sector
Year	A set of dummy variables for the observation year

Table A4. Descriptive statistics by stage

	Early stage					Consolidation stage				
Variable	Obs	Mean	Std. dev.	Min	Max	Obs	Mean	Std. dev.	Min	Max
Inn. performance	1,392	48.542	43.435	0	100	886	36.268	39.549	0	100
Open-Protective	1,392	0.280	0.449	0	1	886	0.208	0.406	0	1
Open-Non-prot.	1,392	0.221	0.415	0	1	886	0.326	0.469	0	1
Closed-Prot.	1,392	0.186	0.389	0	1	886	0.104	0.305	0	1
Closed-Non-prot.	1,392	0.313	0.464	0	1	886	0.362	0.481	0	1
Internal R&D	1,392	63.762	38.344	0	100	886	64.878	38.919	0	100
Size	1,392	22.876	34.713	1	247	886	29.590	37.925	1	240
Group	1,392	0.256	0.436	0	1	886	0.361	0.481	0	1
Scope	1,392	2.319	1.034	1	4	886	2.672	1.074	1	4
High-tech	1,392	0.601	0.490	0	1	886	0.455	0.498	0	1

Table A5. Descriptive statistics. Subsample balanced data

Variable	Obs	Mean	Std. dev.	Min	Max
Inn. performance	1,160	43.839	40.672	0	100
Open-Protective	1,160	0.315	0.465	0	1
Open-Non-prot.	1,160	0.302	0.459	0	1
Closed-Prot.	1,160	0.125	0.331	0	1
Closed-Non-prot.	1,160	0.259	0.438	0	1
Internal R&D	1,160	77.023	28.652	0	100
Size	1,160	27.366	35.314	1	237
Group	1,160	0.317	0.466	0	1
Scope	1,160	2.564	1.062	1	4
High-tech	1,160	0.614	0.487	0	1

Table A6. Estimation results of robustness checks. Random effect OLS regressions

	Full	Early stage	Consol. Stag.	Low R&D	High R&D
	Model 1	Model 2	Model 3	Model 4	Model 5
Internal R&D	0.000	–0.003	0.004	0.009***	–0.012***
	[0.001]	[0.003]	[0.002]	[0.003]	[0.004]
Size	0.143***	0.051	0.336***	0.025	0.137**
	[0.050]	[0.105]	[0.111]	[0.067]	[0.066]
Group	0.117	0.128	0.158	0.103	0.185
	[0.122]	[0.239]	[0.239]	[0.178]	[0.153]
Scope	0.111**	0.101	–0.155*	0.201***	0.03
	[0.048]	[0.089]	[0.087]	[0.075]	[0.060]
High-tech	–0.045	0.239	–0.077	–0.007	–0.083
	[0.104]	[0.223]	[0.227]	[0.157]	[0.129]
Year	Yes	No	No	Yes	Yes
Open-Protec.	0.992***	1.295***	0.865***	0.885***	1.004***
	[0.116]	[0.217]	[0.227]	[0.207]	[0.145]
Open-Non-prot.	0.713***	1.123***	0.416**	0.409**	0.768***
	[0.108]	[0.217]	[0.188]	[0.183]	[0.136]
Closed-Protec.	0.574***	0.804***	1.002***	0.374*	0.723***
	[0.122]	[0.246]	[0.272]	[0.194]	[0.159]
Constant	2.128***	1.755***	1.412***	2.419***	3.283***
	[0.188]	[0.425]	[0.435]	[0.276]	[0.495]
sigma_u	1.000	0.891	1.578	0.936	1.053
sigma_e	1.569	1.491	1.249	1.568	1.510
R^2	0.1	0.079	0.12	0.144	0.088
Rho	0.2879534	0.263019	0.4622864	0.2629549	0.3269441
Wald-Chi2	240.615***	–	–	143.8855***	136.2602***

Standards errors in brackets.
*$P<.10$, **$P<.05$, ***$P<.01$.

Table A7. Estimation results of robustness checks. Attrition

	Full	Early stage	Consol. Stag.	Low R&D	High R&D
	Model 1	Model 2	Model 3	Model 4	Model 5
Internal R&D	–0.001	–0.001	0.002	0.008*	–0.017***
	[0.002]	[0.002]	[0.003]	[0.004]	[0.006]
Size	0.176***	0.198***	0.109	0.048	0.149*
	[0.067]	[0.075]	[0.126]	[0.098]	[0.087]
Group	0.216	0.033	0.387	0.167	0.283
	[0.166]	[0.198]	[0.283]	[0.262]	[0.202]
Scope	0.226***	0.282***	0.115	0.420***	0.076
	[0.066]	[0.078]	[0.112]	[0.111]	[0.080]
High-tech	0.027	0.138	0.142	0.083	–0.09
	[0.143]	[0.175]	[0.285]	[0.228]	[0.172]
Survival	–0.328	–0.353	–0.447	0	–0.949**
	[0.277]	[0.341]	[0.479]	[0.401]	[0.396]
Year	Yes	Yes	Yes	Yes	Yes
Open-Protec.	1.391***	1.276***	1.767***	1.144***	1.486***
	[0.160]	[0.189]	[0.304]	[0.293]	[0.197]
Open-Non-prot.	1.102***	1.091***	1.163***	0.700***	1.188***
	[0.153]	[0.194]	[0.250]	[0.270]	[0.189]
Closed-Protec.	0.819***	0.921***	0.986***	0.547**	1.084***
	[0.169]	[0.197]	[0.351]	[0.278]	[0.215]
Constant	1.379***	1.204***	–0.192	1.608***	3.055***
	[0.259]	[0.298]	[0.466]	[0.401]	[0.653]
sigma_u	1.278***	1.197***	1.908***	1.406***	1.358***
	[0.080]	[0.090]	[0.142]	[0.136]	[0.097]
sigma_e	2.020***	2.024***	1.632***	2.067***	1.880***
	[0.041]	[0.053]	[0.063]	[0.078]	[0.049]
Log Likelihood	–4,027	–2,690.969	–1,313.532	–1,465.846	–2,542.489
No of Obs	2,137	1,392	745	789	1,348
No of left c ~ s	564	340	224	238	326
rho	0.286	0.259	0.577	0.316	0.343
Wald-Chi2	233.1158***	144.3695***	79.32798***	135.529***	133.8893***

Standards errors in brackets.
*$P<.10$, **$P<.05$, ***$P<.01$.

