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Productivity of innovation: the effect of innovativeness on start-up survival

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Abstract
This paper provides arguments supporting the association between different measures of *innovativeness* (i.e., innovation capacity and effectiveness) and the survival of start-ups. Analysing a sample of 9171 innovative Italian start-ups, using Accelerated Failure Time models, we find two main results. First, patents and software licenses seem to strongly predict survival. Second, different measures of innovativeness complement each other: when Research and Development (R&D) expenditures pair with the ownership of patents/software and a skilled workforce, the overall effect on start-up survival gets stronger. It follows that innovativeness, in terms of high skills able to optimize R&D spending, is crucial for the survival of start-ups. Our findings should support policy-making for innovative capability development and "productivity of innovation", and contribute to improving start-ups' credit access and reduce their financial constraints.

Keywords Innovation · Innovativeness · Productivity of innovation · Start-up · Survival analysis

JEL Classification G32 · G38 · O16

1 Introduction

Innovation is the basis of a competitive economy (Porter & Ketels, 2003) and innovation management is crucial for firms' survival (Cefis & Marsili, 2005). However, the competitiveness and growth capacity of firms depend closely on their ability to adopt and

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implement technological changes (Günsel, 2015; Handoko et al., 2014), which, in turn, requires significant resources based on knowledge and human capacity (Audretsch et al., 2014; Grimpe & Hussinger, 2013). For this reason, the paper focuses on firm survival, highlighting the importance of "innovativeness", defined as the ability, thanks to high skills and professionalism to pursue innovation, not innovation in itself (Armbruster et al., 2008), but "effective" innovation (Gebert et al., 2003; Lumpkin & Dess, 1996; Subramanian & Nilakanta, 1996; Wang & Ahmed, 2004). In particular, we investigate the effect of innovativeness on start-up survival by using measures of innovativeness identified by the Italian government for "innovative" start-ups, for which innovation plays a crucial role (Antonietti & Gambarotto, 2020; Cefis & Marsili, 2006; Moroni et al., 2015). We focus on start-ups because of their role in the economic and technological development of Italy as well as the main European countries (Audretsch, 2011; Autio et al., 2014; Fiorentino et al., 2021; Link & Bozeman, 1991; Shepherd & Wiklund, 2009; Wright et al., 2015). In Italy, at the end of 2020, there were 11,893 innovative start-ups (+ 10% compared to 2019), constituting approximately 3.6% of all newly formed joint stock companies and showing a constant increase in share capital. Additionally, innovative start-ups contribute to the digitization process of Italy: 75.7% of them provide services to companies in digital specializations. Moreover, 16% of innovative start-ups in manufacturing are mainly involved in technology. The contribution of innovative start-ups is also important from the point of view of employment: they led to an increase in employment of 12.5% in the two years after 2019 (Ministero dello Sviluppo Economico, 2021). Innovative start-ups also showed great resilience during the Covid-19 pandemic: in 2020–2021 they registered steady positive performance, showing capacity for adaptation and transformation in the evolving economic and social conditions (Ministero dello Sviluppo Economico, 2021). This is consistent with studies (Acs et al., 2009; van Stel et al., 2007) finding that innovative SMEs (Small and Medium Enterprises) are the firms with the highest probability of expanding rapidly, creating net employment and encouraging change in productive specialisation in their countries.

Despite the importance of innovation in firm dynamics (Alvarez & Busenitz, 2001; Balachandra & Friar, 1997; de Brentani, 1991; Di Benedetto, 1999; Pellegrino et al., 2012; Velu, 2015), there is as yet little empirical research on the relationship between innovativeness and firm survival. In general, the existing literature finds that innovation positively affects it (Ugur & Vivarelli, 2021). However, a set of factors including innovation types, intensity and scale (e.g., Ugur et al., 2016),[1] time-specific and industry-specific technological opportunities (Cefis & Marsili, 2019), firms' intrinsic characteristics (Cefis & Marsili, 2005), the role of market power (Hall, 2011; Hall et al., 2010), the level of profitability (Fiorentino et al., 2021) and efficiency (Hopenhayn, 1992; Jovanovic, 1982), the complexity of the innovation process (Buddelmeyer et al., 2006; Heredia Pérez et al., 2019), contextual factors (Song et al., 2007) and, above all, the way innovation is measured (Dziallas & Blind, 2019; Mendoza-Silva, 2021), can lead to heterogeneity in the effect of innovation on firm survival (Dalglish & Newton, 2002; Ugur & Vivarelli, 2021). In the light of this, this paper focuses on innovativeness considering the innovativeness measures identified by the Italian government for a start-up to be considered innovative (see Sect. 2).

Our research makes the following major contributions. First, we extend the literature on the impact of innovation on SMEs highlighting the relevance of "innovativeness". This

[1] Ugur et al. (2016) demonstrate that innovation increases the probability of survival when it increases from a low initial level, but it may reduce the probability of survival when it increases from a high initial level, due to diminishing scale returns or increased risks.

concept has multiple aspects, including the capacity and propensity to create or adopt new products, businesses and organizations, open up new markets, support new ideas, novelty, experimentation and creative processes (Wang & Ahmed, 2004). We find that different measures of innovativeness have a specific effect on survival: qualified workforce and patent/software ownership have positive effects, while the Research and Development (R&D) spending has a negative impact on survival. Second, there seems to be complementarity between the different innovation measures: when R&D expenditures pair with skilled workforce and patent/software ownership, the overall effect on start-up survival gets stronger. The existence of these complementarities highlights how innovativeness, i.e., the need to manage spending on innovation processes in an informed and effective way (the innovation capacity), is crucial for entrepreneurial firms' survival. Therefore, entrepreneurs' skills, expertise and vision are crucial to optimally manage R&D spending and select investments with the highest return. Our findings should support policymakers develop the innovative capabilities of start-ups that foster "productivity of innovation", which, in turn, should facilitate access to better financing conditions.

The structure of the paper is as follows. Section 2 and 3 present the institutional background and the theoretical framework respectively. Section 4 describes the methods and Sect. 5 reports the results. Section 6 discusses the implications and concludes.

2 Institutional background

SMEs account for 99% of all EU enterprises, employ around 100 million people and account for more than half of Europe's Gross Domestic Product (GDP).[2] SMEs therefore contribute strongly to the economic growth of the EU and, together with start-ups, with their high innovation potential, lead the transformation of the EU private sector. The European Commission recognized the economic significance of SMEs and start-ups, launching, in 2014, the *Startup Europe Initiative*,[3] under the EU Research and Innovation Program Horizon 2020. The goal is to expand the European entrepreneurial ecosystem through improvement of institutions and infrastructures, in order to have an increasing direct beneficial effect on jobs and growth (European Commission, 2016). In this regard, the European Start-up and Scale-up Initiative[4] is formulated from the perspective of the Single Market, as part of the *Single Market Strategy*. In fact, start-ups scaling up into bigger firms increase EU innovation and competitiveness, strengthening the economy in the EU. This is consistent with studies confirming that innovation fosters aggregate economic growth (e.g., Daveri, 2002; Mankiw et al., 1992; Ortega-Argilés et al., 2014). The increase in European initiatives and national policy actions in support of innovative and high-tech start-ups, which have relationships with investors, accelerators, business networks, universities and the media, demonstrates the need for innovation for companies and the importance of identifying effective innovation measures (e.g., Comacchio et al., 2012; Hilkenmeier et al., 2021; Kang & Park, 2012; Jia et al., 2019).

Innovative entrepreneurship policy initiatives are also implemented at the national level (Moss, 2011), which allows for coherent and legitimate initiatives on tax, labor and

[2] Source: https://single-market-economy.ec.europa.eu/smes_en and https://single-market-economy.ec.europa.eu/smes/sme-strategy/sme-performance-review_en.

[3] https://digital-strategy.ec.europa.eu/en/policies/startup-europe.

[4] Source: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016DC0733.

financial markets (e.g., Acs et al., 2014). Focusing on EU member states, among the innovative entrepreneurship initiatives, there is French *Station F*,[5] a program aimed at developing ecosystems supporting talented foreign entrepreneurs to develop their innovative idea in France by granting a residence permit. This is a program which also grants access to funds, networks and partners, as well as incubators and hubs. In Germany, the *Digital Hub Initiative*[6] aims at strengthening the entrepreneurial ecosystem and the network between established and early stage start-ups. In Spain, the *Enisa Participative Loans*[7] provide financial incentives for innovative start-up projects and the *Rising Startup Spain*[8] aims to attract international entrepreneurs and talents and offer a 6 month acceleration program.

In Italy, there is increasing attention to innovative entrepreneurship, as shown by the high number of existing initiatives, including: (i) the *Clab (Contamination Lab),*[9] aimed at providing university students, from both technical-scientific and humanistic fields, with a stimulating environment for the development of innovative projects; (ii) the *Italian Startup Visa*,[10] aiming to support non-EU entrepreneurs who want to establish an innovative start-up in Italy. It enables talented people from all over the world to obtain a 1-year self-employment visa for Italy, freely renewable at expiration if the start-up is up and running; (iii) the *Italian Startup Act,* noted above, which provides regulatory advantages, financial benefits, tailor-made labour measures and other support instruments to innovative start-ups and SMEs.

It is interesting to note that, given the large number of initiatives and regulations, there are differences in the definition of an innovative start-up. Audretsch et al. (2020) identify different approaches. For example, the "New firms" approach, such as that of the *Italian Startup Visa* and German *Digital Hub Initiative*, does not require the firm to be innovative, although the declared aim is to support innovative entrepreneurship. The underlying assumption is that entrepreneurship in general is an intrinsic source of dynamism that implies innovation. Another approach is "Self-declaration", as seen in the Spanish *Enisa Participative Loans* and *Rising Startup Spain*, in which innovativeness is a requirement for support, and the burden of proof rests with the applicant firm. The process involves self-declarations in which the nature and the innovative character of the entrepreneurial project are stated, and which are then verified by the program operator or an independent verification service.

However, some initiatives are characterized by a "growth-oriented" approach, such as the French *Station F*, because they are targeted to growth-oriented start-ups and not necessarily directly to innovative start-ups, assuming that, in the current global context, growth orientation or scalability are almost synonymous with innovation. Here too, the innovativeness of the start-up in some programs is self-declared by the firm and verified by the national government: this attribute is related to a general certification of the firm itself, a sort of *status*, that can be used for specific support program applications, as well as for other more generic benefits, such as tax reductions or hiring facilitations. This "Certification" approach characterizes the *Italian Startup Act* (Decree Law no.179/2012, approved, with amendments, by Law no. 221 of 17 December 2012). In Italy, innovative start-ups

5 https://french-tech-international.stationf.co/.

6 https://www.de-hub.de/en/.

7 https://www.enisa.es/en.

8 https://www.investinspain.org/content/icex-invest/en/rising-up-in-spain.html.

9 https://clab.cineca.it/.

10 https://italiastartupvisa.mise.gov.it/.

have to fulfil specific requirements. They must: be less than 60 months old; be based or have a production branch in Italy; have revenues lower than €5 million and no distribution of profits; have a specific core business (Ministero dello Sviluppo Economico, 2021). Moreover, a start-up needs to meet at least one of the three following conditions to be considered innovative:

a. spending on R&D and innovative activities is equal to at least 15% of the higher of either turnover or cost of production;
b. the firm employs a highly qualified workforce (at least 1/3 of employees hold Ph.Ds., are Ph.D. students or researchers, or at least 2/3 of employees hold a Master's Degree);
c. the firm holds a patent or owns a software licence.

Innovative start-ups receive support from the Italian government in terms of lower costs for setting up the company, fewer bureaucratic and administrative procedures, more flexible rules for employee hiring and remuneration, and access to specific financial support. All these measures are designed to facilitate business and innovation processes (Guerrero & Urbano, 2019), consistently with the international policy orientation to innovative entrepreneurship (Acs et al., 2014). This paper aims to provide arguments supporting the association between *innovativeness* and the survival of start-ups, which is the basis of all the national initiatives mentioned. Indeed, understanding the effect on start-up survival is crucial to defining national policies capable of pursuing coherent and legitimate initiatives on tax, labour and financial markets. However, we focus on the context of Italy, where, as specified, the innovativeness of the start-up is verified by the government. This makes it possible to analyse the innovativeness measures approved by the government to define an innovative start-up. The effect on survival of these measures could potentially guide future choices in terms of policy and regulation.

3 Literature review

Firm survival and its determinants have been widely investigated in literature. The factors that affect firm survival can be classified into those that are specific to the firm (e.g., size, type), entrepreneur (e.g., age, education), industry (e.g., manufacturing, technology-based), region, or a combination of these. Audretsch (1991) states that the size of the firm is an important determinant of firm survival, as the ability to attract financial capital increases with firm size. Persson (2004) shows that firm survival increases with age and the size of the firm, as well as the level of educational attainment of the employer and entrepreneurial team (Bolzani et al., 2019). Esteve-Pérez et al. (2018) study the role played by firm age and productivity in its survival across three stages of the life cycle: in the 'early' stage, age is negatively correlated with hazard rates while productivity is not; productivity is associated with lower hazard in the 'mature' stage, while age does not play a significant role for firm survival; in the 'intermediate' stage, both age and productivity play a role in reducing firms' hazard rates. Boyer and Blazy (2014) find that the variables related to human capital or personal characteristics have a significant and sustainable impact on the survival of innovative companies. Some studies (e.g., Strotmann, 2007) find that the specific conditions in the sector are favourable to firm survival. Others (Buehler et al., 2012; Keeble and Walker 1994; Reynolds et al., 1994; Renski, 2011) suggest that firm entry and exit are more closely associated with regional economic conditions. Acs et al. (2007) investigate the influence of a region's human capital stock on firm survival and find a negative relationship between the high school dropout rate and new firm survival in the service sector.

Several studies include innovation among the determinants of firm survival (Aghion & Howitt, 1998; Aghion et al., 2015; Klette & Kortum, 2004). This paper is related to this strand of literature and focuses on the impact of innovation or, more precisely, of "innovativeness" (i.e., innovation capacity) on survival of start-ups. Indeed, innovation is a key issue for SMEs in general (Ghura et al., 2022), and for start-ups in particular (Fiorentino et al., 2021; Innocenti & Zampi, 2019). Some researchers find that innovation reduces the sensitivity of start-ups to adverse macroeconomic shocks, thus representing a driver of their growth (Geroski et al., 1993, 1997). In this regard, Cefis and Ciccarelli (2005) hypothesise that innovative firms have competencies and behavioural patterns that enable them to weather economic shocks and market challenges. Other researches (e.g., Ahmed et al., 2020; Song et al., 2007) analyse the impact of innovation on firm survival examining the effects on the performance.[11] Firm survival is in fact considered as an indicator of post-entry performance, where the selection process leads productive firms to survive and grow, and others to stagnate and ultimately exit (Audretsch & Mata, 1995). Some authors examine the impact of innovation on competitiveness (Banbury & Mitchell, 1995; Nelson & Winter, 1982; Porter, 1980; Shoham & Fiegenbaum, 2002), and absorptive capacity (Zahra & George, 2002), in improving dynamic capabilities (Eisenhardt & Martin, 2000; Teece et al., 1997) and in reducing costs (Cohen & Klepper, 1996), thus contributing to firm survival. However, quantifying and evaluating innovation competences and practices is a significant and complex issue for many contemporary organizations (Frenkel et al., 2000).

Existing literature finds conflicting results regarding the effects of innovation on firm survival. Consistently with authors who argue that innovation creates value for SMEs (Zhang et al., 2020) and contributes to employment growth (Hall et al., 2008), many studies show a positive effect of innovation on start-ups' survival rates (Arrighetti & Vivarelli, 1999; Audretsch, 1995; Cefis & Marsili, 2006; Colombelli et al., 2013, 2016; Helmers & Rogers, 2010). However, some researchers point out that the level of impact of the innovation varies according to whether it is a product or a process innovation (Cefis & Marsili, 2005) and according to its degree (Saemundsson & Dahlstrand, 2005): in the case of a major innovation, being innovative becomes a negative factor for the survival of SMEs (Buddelmeyer et al., 2010). Other reasons for which innovation does not always have a beneficial impact on companies include resistance to innovation (Ram & Jung, 1991), failure of innovation (Berggren & Nacher, 2001; Damanpour, 1991; Hultink & Atuahene-Gima, 2000), the fact that pursuing innovation sometimes leads to risky and complicated processes (Hyytinen et al., 2015; Samuelsson & Davidsson, 2009), and to unpredictable returns (Scherer & Harhoff, 2000). Some studies (Brown et al., 2012; Minetti, 2011) state that innovative start-ups have few collateralizable assets and long and uncertain payback times, and, as a consequence, they have limited access to external credit (Ferrucci et al., 2021), which determines a greater likelihood of failure (Berger & Udell, 2006). Moreover,

[11] Some studies find that innovation contributes to improving firms' performance, in terms of both profitability and competitiveness (Audretsch, 2004; Block et al., 2016; Cozza et al., 2012; Dosi et al., 1995; McEvily et al., 2004; Roberts, 1999; Santi & Santoleri, 2017), others show that firms' performance is negatively correlated with innovation (McGee et al., 1995; Vermeulen et al., 2005), while others find that innovation has no impact on performances (Birley & Westhead, 1990; Heunks, 1998).

innovative entrepreneurs may have a particular exit strategy in mind (DeTienne et al., 2015) and this may lead to an increase of the firm's risk profile.

However, the entire innovation process requires firms to have the organizational resources and ability to reap its benefits (Branzei & Vertinsky, 2006; Howell et al., 2005; Junkunc, 2007; Sethi & Sethi, 2009; Thornhill, 2006). Consistently with these findings, in this paper we consider the concept of "innovativeness", i.e., the aforementioned innovation capacity or, in other words, the capacity to make "effective innovation" (Gebert et al., 2003).

Furthermore, as noted by Rosenbusch et al. (2011), how innovation is measured is critical for understanding the effect on firm survival (Dewangan & Godse, 2014; Dziallas & Blind, 2019; Heredia Pérez et al., 2019; Love & Roper, 2015). Esteve-Pérez and Mañez-Castillejo (2008) find that firms that develop firm-specific assets through advertising and making R&D enjoy better survival prospects. Park et al. (2010) confirm that R&D facilitates firm survival. However, some authors (e.g., Ericson & Pakes, 1995) find that the effect of R&D investment on firm survival is indeterminate, as it depends on the stochastic outcomes of the investment, the success of other firms, and the competitive pressure from outside the industry. Coad and Guenther (2013) examine degrees of diversification related to product innovation and find that survival prospects are enhanced by innovativeness, "if not undertaken too hastily" (p. 634). In this regard, the results of Koch et al. (2013) show that, *inter alia*, high-skilled and young workers are conducive to survival. Helmers and Rogers (2010) study a cohort of UK-based limited liability companies and show that owning intellectual property is positively associated with survival. As Buddelmeyer et al. (2010) note, the empirical measures of innovativeness are frequently *ex-post* indicators that tend to capture successful innovations and innovators (Artz et al., 2010; Mairesse & Mohnen, 2002; Pandit et al., 2011; Santarelli & Vivarelli, 2007). Wagner and Cockburn (2010) investigate the survival prospects of Internet companies after an Initial Public Offering (IPO) on NASDAQ and find that patenting is positively associated with firm survival. Colombelli et al. (2013) examine how aspects of firms' patent stocks affect survival and find that innovation enhances survival prospects. Buddelmeyer et al. (2010) use patent and trademark applications as well as grants to derive measures of flows and stocks of innovativeness, and observe that past success in radical innovation enhances survival prospects. However, they also find that firms are more likely to fail immediately after investing in radical innovation, as measured by submitted patent applications. It is thus essential to refer to specific measures of "innovativeness", which can positively contribute to start-up survival (Roberts, 1990; Wolff, 2007). In this regard, we study the effect of conditions (and their complementarities) identified by the Italian government for start-ups to be considered innovative (see Sect. 2) and we formulate the following research question: *What is the effect of different measures of innovativeness on start-up survival?*

The literature which uses data on Italian innovative start-ups is rich. Fiorentino et al. (2021) evaluate the impact of innovativeness on the growth of innovative start-ups studying a sample of 1170 firms, and find that differences in growth can be explained by the different levels of innovativeness. Colombelli et al. (2020) analyse a sample of more than 1600 Italian young innovative companies to investigate to what extent a comprehensive set of policy measures recently focused on alleviating the hurdles suffered by young innovative companies is associated with the choice of such companies to protect their innovation. Colombelli et al. (2020) find that the use of financial policy measures is associated with both formal and informal instruments, while labour policy measures are only associated with formal instruments. Audretsch et al. (2020) review 38 policy initiatives from around the world, including Italian ones, and develop a process framework highlighting how policy initiatives, managerial issues and research approaches are conceptually different, depending on the specific stage of firm development. Calcagnini et al. (2016) examine a sample of 1953 start-ups to study the role played by knowledge and technology transfer services of Italian universities in attracting innovative start-ups, and find that geographical proximity favours the transfer of knowledge and technology from universities to industries, and is therefore a positive factor for regional economic development. Colombelli (2016) investigates the relationship between the features of local economic systems and the creation of innovative start-ups. Analysing a sample of 1676 innovative start-ups, she finds that the size, variety and similarity of the knowledge stock play a key role in shaping the creation of innovative start- ups.

In line with the existing literature, we analyse the effects of innovativeness on survival of Italian innovative start-ups, addressing aspects related to the policy, and the contribution of start-ups to economic growth. However, we investigate a larger sample than those used on average by previous studies and, like Fiorentino et al. (2021), we use specific innovativeness measures. However, while Fiorentino et al. (2021) investigate the role of innovativeness on start-up performance (i.e., the growth rate of the revenue from sales), we focus on the effect of innovativeness on the survival of start-ups.

Table 10 in Appendix A summarizes the key details of the studies briefly surveyed above. It focuses on the main determinants of firm survival, including innovation (Panel A), the importance of how innovation is measured (Panel B) and the role of innovation on Italian innovative start-ups (Panel C).

4 Empirical design

4.1 Data and variables

Our dataset is constructed by combining two firm-level databases: the Italian Company Register, which contains a specific section for innovative start-ups, and the AIDA Bureau Van Dijk (AIDA). The first contains information about innovative start-ups and the second contains financial data for most SMEs covered.

We obtain from the Italian Company Register the list of all the firms which are present in the special section of the Italian innovative start-ups in April 2022, for a total of 14,484 firms. We then search in the AIDA database each start-up financial data by means of the *Tax Code Number*, which uniquely identifies each firm operating in Italy. The *Tax Code Number* is then used to match the two datasets. We discard start-ups created after 2020 because of lack of data, and also discard those that interrupted operations for motivations different from bankruptcy, such as M&A, when this information is available in AIDA.[12] This pre-processing phase yields a sample of 9171 innovative start-ups which were registered in the Italian Company Register at the time of consultation: we set the period for the analysis between 2013 and 2021, for a total of 23,210 firm-year observations. Start-ups remain at risk on average for about 1169 days with a minimum of 365 days and a maximum of 2188 days. The sample includes 512 defaults. Table 1 presents the description of time to default for the firms in our sample.

[12] From the initial sample of start-ups, we discarded 4,524 start-ups because they were set up after 2020, 87 because they ceased operations for motives different from bankruptcy and 702 due to the lack of data.

The study focuses on the survival of innovative start-ups. We are aware that failure is a complex process and different definitions have been specified in the literature (Balcaen & Ooghe, 2006). Moreover, the process of bankruptcy might have long period of time between its initial phase and the actual termination of a firm, and the firm might have already stopped its operations for good. To overcome this issue, we decided to operationalize failure as the last year in which each start-up presented an annual report to the Italian Company Register. This decision stems from two main considerations. The first consideration is theoretical: firms which are in a healthy financial condition do not benefit from not depositing their balance sheets items and, thus, hiding their financial status from stakeholders (Yuthas et al., 2002). The second consideration is legal: once a year, innovative start-ups are required by law (Ministero dello Sviluppo Economico, 2022), to confirm the fulfilment of the requirements to be registered in the special section in order to retain the status of innovative start-up. Since many of these requirements are inferable from financial statements, and considering how advantageous are the benefits provided by the inscription into the registry, there is no reason for innovative start-ups not to register their balance sheets on the Italian Company Register. This operationalization allows us to define clearly the failure of a start-up, without incurring problems related to the fact that a firm may, in fact, cease its operations even though it is still registered as active. It excludes possible "zombie firms" from our sample, and is a common approach in the literature on entrepreneurial firms (Bartoloni et al., 2021; Ferragina & Mazzotta, 2014). Based on these considerations, survival time is defined as the number of days from the set-up of a start-up until its failure (or right-censoring for non-failed firms). In order to calculate this period of time, we obtain the date of foundation and the date of the last available Annual Report from the AIDA database. Survival time is defined as the difference between the foundation date and the year after the last available annual report[13]: this construct is used as our dependent variable in the Accelerated Failure Time models.

Our key covariates are related to innovativeness. We exploit data from the Italian Company Register and we dissect innovativeness into three different aspects related to the three requirements indicated in the Startup Act: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; and REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise. These variables are collected directly from the special section of the Italian Company Register, where, for each start-up, they indicated which requirements were met[14] at the time of registration into the Register.

To rule out possible other explanations for our dependent variable, we include in our analysis a set of control variables related to the entrepreneurs and the firms. Some researchers, in fact, find that there is a link between the characteristics of the entrepreneurs, the dynamics of the entrepreneurial teams and the success of new ventures (Amason et al., 2006; Del Bosco et al., 2021; Hashai & Zahra, 2022), including survival (Bates, 1990; Gimmon & Levie, 2010). In particular, female, young and foreign-born entrepreneurs

[13] For example, if a firm published its last annual report in 2018, we assume that the firm survived until 31/12/2019.

[14] The requirements are self-reported by the entrepreneur who registers her own firm to the special section. These requirements are then subject to spot checks by the Italian government in the following years.

Table 1 Description of time to default

Category	Total	Per subject			
		Mean	Min	Median	Max
Number of subjects	9171	–	–	–	–
Number of records	23,210	2.53	1	2	5
Entry time (first)		0	0	0	0
Exit time (final)		1169.66	365	1120	2188
Subjects with gap	0	–	–	–	–
Time on gap	0				
Time at risk	10,726,920	1169.66	365	1120	2188
Failures	512	0.056	0	0	1

adopt specific start-up processes (Demartini, 2018; Kazmi, 1999; Neville et al., 2014; Yukongdi & Lopa, 2017), which may, in turn, affect also the survival of their firms (Denk et al., 2012; Fertala, 2008; van Praag, 2003). We follow the approach of Del Bosco et al. (2021) and measure the prevalence in the start-up capital/board of directors of each category as follows[15]:

$$\frac{\begin{array}{c}(\textit{\% of startup capital owned by a particular category} + \\ \textit{\% of board of directors belonging to a particular category})\end{array}}{2} > 50\%$$

We thus indicate the prevalence of each category in the governance of the start-up using a dummy variable equal to 1 if the ratio above is higher than 50%, and 0 otherwise.

As for the control variables related to the intrinsic characteristics of the firm, many authors find what is called a "liability of smallness" (Freeman et al., 1983). This means that bigger firms tend to survive longer than their smaller counterparts (Audretsch & Mahmood, 1995; Colombelli et al., 2016). Therefore, we also include in our model the variable SIZE, calculated as the natural logarithm of *Total Assets*. Many studies also highlight the importance of financial performance and financial structure on the survivability of young firms (Baumöhl et al., 2020; Modina & Pietrovito, 2014). Indeed, Ferrucci et al. (2021) show how more profitable firms tend to survive longer. We thus include as a control variable the *Return on Assets* (ROA), as a proxy of a start-up's profitability; a firm's financial structure is also a key factor that influences its survival probabilities (Cefis et al., 2020; Zingales, 1998): to control for the level of indebtedness of firms, we consider LEVERAGE, calculated as the ratio between *Total Debt* and *Equity*. As well as internal factors, spatial factors also affect the survival chances of start-ups (Falck, 2007; Manjón-Antolín & Arauzo-Carod, 2008). In fact, not only do firms benefit from being located in metropolitan and densely populated areas (Fotopoulos & Louri, 2000), but their survival rates are higher in regions where favourable business conditions are present (Buehler et al., 2012). This is particularly important in the context of Italy, where there is a clear difference between the North, usually more developed and favourable to business, and the South, characterized

[15] This is the same approach used by Italian Government to measure the prevalence of each category in the governance of each start-up (see, https://www.mimit.gov.it/images/stories/documenti/1_trimestre_2023_1_cruscotto_startup.pdf, [accessed 25 November 2023]). We follow this approach so that our analysis is consistent with literature and policy.

Table 2 Descriptive statistics

Variable	Total Sample			Default			Non Default			Test Default vs. Non Default	
	Obs	Mean	Std. Dev	Obs	Mean	Std. Dev	Obs	Mean	Std. Dev	Δ	*p-value*
DEFAULT	23,210	0.02									
REQ1	23,210	0.63		512	0.68		22,698	0.63		−0.058	(0.007)
REQ2	23,210	0.29		512	0.24		22,698	0.29		0.054	(0.008)
REQ3	23,210	0.25		512	0.16		22,698	0.26		0.10	(0.00)
WOMEN	23,210	0.14		512	0.19		22,698	0.14		−0.055	(0.00)
YOUNG	23,210	0.13		512	0.13		22,698	0.13		0.005	(0.763)
FOREIGN	23,210	0.03		512	0.05		22,698	0.03		−0.02	(0.015)
ROA	23,210	−8.51	47.83	512	−15.88	56.33	22,698	−8.35	47.61	7.536	(0.0028)
SIZE	23,210	4.40	1.62	512	4.01	1.68	22,698	4.41	1.62	0.39	(0.00)
LEVERAGE	23,210	29.36	4081.72	512	8.16	188.79	22,698	29.84	4127.40	21.69	(0.4489)
INCUBATOR	23,210	0.55		512	0.48		22,698	0.55		0.063	(0.005)
GREEN	23,210	0.15		512	0.15		22,698	0.15		−0.001	(0.965)

Table 2 presents the descriptive statistics of failed and non-failed start-ups. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise; GREEN is a dummy variable equal to 1 if the start-up is defined as a "high technological value company in energy related fields", and 0 otherwise. In the "*p-value*" column, we report the resulting *p-value* of an unequal variance t-test for the difference in means of the variables ROA, SIZE and LEVERAGE, and the *p-value* of a Pearson's Chi-squared test for all the remaining variables by less ideal conditions (Rungi & Biancalani, 2019).[16] In order to control for local conditions, we add to our model regional fixed effects. Moreover, it is known that the overall innovation ecosystem stimulates the creation and the survival of innovative firms (Bandera & Thomas, 2018). Therefore, we obtain the list of official incubators and science districts registered in the special section of the Italian Company Register: we then create a dummy variable, INCUBATOR, equal to 1 if a start-up is located in the same province of the incubator/science park, and 0, otherwise.

Table 2 provides descriptive data regarding the firms in our sample. It shows that about 63% of the innovative start-ups in our sample focus on the first requirement, while only about 25% of the start-ups focus on the third one. Moreover, almost one third (29%) of all start-ups met the second requirement. We note that 14% of start-ups are led by women, 13% are led by young entrepreneurs, while only 3% of innovative start-ups are led by foreign-born people. Table 2 also shows the differences between failed and non-failed firms. Defaulted firms tend to fulfil more the first requirement (68%) than non-defaulted firms (63%). On the other hand, start-ups which did not default in our sample focus more on the second requirement (29%) compared to the failed start-ups (24%). This difference is even clearer looking at the third requirement, where there is a 10% gap in favour of non-defaulted start-ups. With regards to the entrepreneurs' characteristics, a higher percentage of failed firms (19%) appear to be run by women compared to non-failed firms (14%). Moreover, firms that did not default appear to be bigger in size, more profitable and to have higher debt levels. Finally, non-failed firms tend to cluster near incubators or science parks. Table 3 presents the correlation between the variables used in the analysis.

4.2 Methodology

A survival analysis is conducted, with the variable of interest *time* from an initial event to another (destination) event. The initial event is the foundation date, and the destination event is the date of default. A subject is said to be *at risk* for the destination event after the initial event has occurred. Survival data requires specific methods because subjects may show incomplete information about their survival times due to time constraints in the research design. In cases where the entire history of a subject is not known, the fact that it survived up until the end of the study can still provide very valuable information. Two types of censoring are used to overcome this issue in survival analysis: observations can be left- or right-censored. *Left censoring* (also called *delayed entry*) is used when information about the starting point of a subject is missing, i.e. the subject enters the study after having already been at risk for a period. In this case, observation of a start-up starts some time after its foundation date. *Right censoring* is used when the exact survival time of a subject is not known. This might happen for two reasons: either the event of interest does not occur before the end of the observation period (*end-of-study censoring*); or a subject may stop being at risk because of a competing risk, which is a different event other than the one of interest (*loss-to-follow-up censoring*). In the case of loss-to-follow-up censoring it is usually assumed that censoring is non-informative, i.e. survival times for the competing events are conditionally independent (Rabe-Hesketh & Skrondal, 2012). Given the construction of our dataset, only end-of-study censoring is used, because every start-up is observed from the day of foundation until the date of default or the end of the study.

[16] Regions are Italian regions, corresponding to European Union NUTS 2 regions.

Table 3 Simple correlation matrix

	REQ1	REQ2	REQ3	WOMEN	YOUNG	FOREIGN	ROA	SIZE	LEVERAGE	INCUBATOR	GREEN
REQ1	1										
REQ2	−0.473***	1									
REQ3	−0.387***	−0.171***	1								
WOMEN	−0.0163*	0.0314***	−0.0163*	1							
YOUNG	0.0533***	−0.0394***	−0.0407***	0.0273***	1						
FOREIGN	0.0172**	−0.0390***	0.00689	0.0961***	0.0140*	1					
ROA	−0.0177**	0.0364***	−0.00578	−0.00537	−0.0288***	−0.0358***	1				
SIZE	−0.00291	−0.0526***	0.0997***	−0.0966***	−0.109***	−0.00981	.210***	1			
LEVERAGE	−0.00929	0.0109	0.0109	−0.00124	−0.00630	−0.00111	0.00108	0.0153*	1		
INCUBATOR	0.0248***	0.00702	−0.0261***	−0.0354***	−0.0140*	0.00742	−0.0456***	0.0898***	−0.00744	1	
GREEN	−0.0830***	0.106***	0.0611***	0.0144*	−0.0469***	−0.00832	0.0250***	0.0181**	0.0153*	−0.0648***	1

Table 3 presents the simple correlation between the variables used in the analysis. *, **, *** indicate significance levels at 10%, 5% and 1%, respectively. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise; GREEN is a dummy variable equal to 1 if the start-up is defined as a "high technological value company in energy related fields", and 0 otherwise

Following the duration analysis approach, the time to default is denoted *t*, which is the realization of a random variable *T* with a probability density function *f*(*t*) and a cumulative distribution function *F(t)* (Rabe-Hesketh & Skrondal, 2012). Therefore, the probability of a start-up to survive to time *t* or beyond is given by the survival function *S*(*t*):

$$\mathrm{S(t)} = Pr(T \geq t) = 1 - F(t) \tag{1}$$

where *F*(*t*) is a cumulative density function. Alternatively, the distribution of survival time *t* can be described using the so-called *hazard function h*(*t*), which represents the instantaneous probability of a start-up to default at time *t*, given that it has survived until time *t* (Kiefer, 1988). The hazard function is defined as:

$$\mathrm{h(t)} = \lim_{\Delta \mathrm{t} \to 0} \left\{ \frac{Pr(t \leq T < t + \Delta t | T \geq t)}{\Delta \mathrm{t}} \right\} \tag{2}$$

There are several ways to model survival time in duration analysis, and our analysis consists of two steps. First, we follow a full non-parametric approach to assess the impact of innovation on start-up survival. We provide survival time estimates using the Kaplan–Meier (KM) estimator of *S*(*t*), which is a frequency estimator that does not make ex-ante assumption on the distribution of default times (Kaplan & Meier, 1958). The KM survival times estimation is given by:

$$\widehat{S}(t) = \prod_{t_k \leq t} \left(1 - \frac{d_k}{n_k} \right) \tag{3}$$

where d_k represents the number of failures at time t_k, n_k is the number of firms in the risk set at time t_k, and the product is over all intervals *k* that end before time *t*. We estimate KM curves for the entire sample and for each subsample based on the three innovativeness dimensions, and we test the equality of the curves using Logrank test.[17] While KM curves are useful for an exploratory analysis of the survival patterns, they do not reveal possible confounding effects of other covariates on the estimated survival times. The second step therefore uses a parametric approach, called Accelerated Failure-Time (AFT) model.[18]Therefore, our model can be written in a log-linear form as follows:

$$\begin{aligned} ln(T_i) = \beta_0 &+ \beta_1 INPUT_i + \beta_2 ORIENTATION_i + \beta_3 OUTPUT_i + \beta_4 FEMALE_i \\ &+ \beta_5 YOUNG_i + \beta_6 FOREIGN_i + \beta_7 ROA_{i,t-1} + \beta_8 SIZE_{i,t-1} \\ &+ \beta_9 LEVERAGE_{i,t-1} + \beta_{10} INCUBATOR_i + REGION\_FE \\ &+ SECTOR\_FE + YEAR\_FE + \sigma \varepsilon_i \end{aligned} \tag{4}$$

where $\ln(T_i)$ is the logarithm of survival time of start-up *i*, while σ and ε_i represent a scale parameter and the error term, respectively. The covariates of the model are presented in Sect. 4.1. Moreover, to consider any difference at regional, sectoral and year levels not

[17] The Logrank test, also known as the Mantel-Cox test, is a non-parametric test used to find whether two samples show the same survival distributions. It is appropriate when data are right skewed and censored.

[18] While the standard approach in modelling firm survival times (Manjón-Antolín & Arauzo-Carod, 2008) is the Cox Proportional Hazards model (Cox, 1972), we opt for AFT because the underlying assumptions of the Cox model are not satisfied in our setting. Moreover, AFT models are also more robust to omitted variable bias (George et al., 2014; Keiding et al., 1997; Rabe-Hesketh & Skrondal, 2012). For a more detailed explanation of this choice, see Appendix B.

captured by other independent variables, region, sector and year fixed effects are added to the model. Finally, note that all continuous variables are lagged by one year, in order to partially prevent endogeneity issues. The parameters of the model are estimated via maximum likelihood. When using an AFT model, we need to choose a functional form for ε_i. The parametric distribution assumed for the error term give the name to the model: the most common choices in the firm survival literature are the Exponential, the Weibull, the Log-normal and the Log-logistic models (Manjón-Antolín & Arauzo-Carod, 2008). The model is usually chosen by a graphical inspection of the Cox-Snell residuals plot and by a comparison of the Log-Likelihood (ll), the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), as noted by George et al. (2014). We thus estimated all four models, and all of the criteria indicated that the Log-normal model is a good fit for our data.[19] Our choice is also supported by the smoothed hazard estimates plotted in Fig. 1, which shows an initial positive duration dependence followed by a negative duration dependence, in line with Wagner (1994) and Falck (2007), who find that small firms hazard rates tend to reach a maximum around the fifth year after startup and then decrease monotonically. Moreover, the use of the Log-normal distribution is becoming a common choice for modelling small firms' survival in the entrepreneurship literature (Colombelli et al., 2013, 2016; Ferrucci et al., 2021; Strotmann, 2007).

5 Results

5.1 Univariate results

In order to discover how different dimensions of innovativeness influence the survival of innovative start-ups, we compare the survival rates of different groups according to the three requirements considered. Table 4 shows the survival rate estimates for the different groups. It shows that in the whole sample, after 5 years, slightly fewer than 90% of the start-ups are still operating. Looking at the different subgroups, the start-ups characterized by the first requirement show slightly lower survival rates than the whole sample. Start-ups which focus on the other two requirements show better survival rates: at the end of the period, the group characterized by the second requirement show a survival rate 1% higher than the whole sample. And start-ups characterized by the third requirement show even better results, with survival rates more than 3% higher than the entire sample. With *p*-values approximately equal to zero, all Logrank tests confirm that the differences between survival rates are statistically significant in all three cases.

These results are confirmed by the estimation of the Kaplan–Meier curves, shown in Fig. 2. Start-ups characterized by REQ1 show lower survival rates than the rest of the sample, while the other two requirements appear more important as determinants of innovative start-ups' survival.

The results of the univariate analysis thus provide preliminary empirical evidence that, of the three innovativeness requirements, only REQ2 and REQ3 appear to be beneficial for start-ups' survival. However, these findings are given by a univariate analysis and do not

[19] Appendix B presents the results and a more detailed explanation for choosing the Log-normal parametric distribution for the error term.

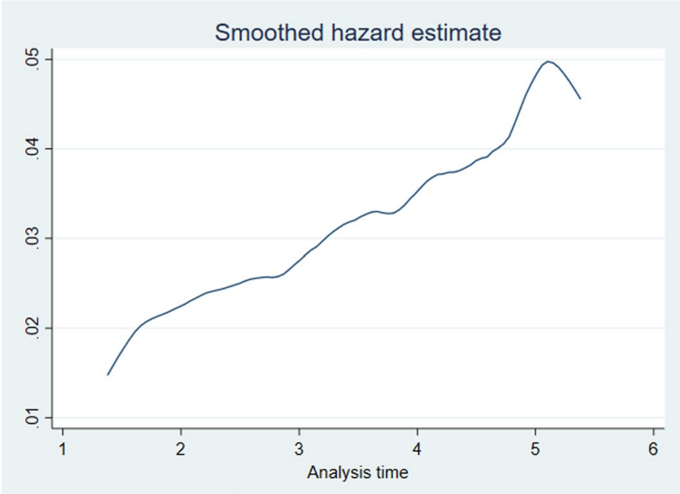

Fig. 1 Smoothed hazard estimates of the failure rates (analysis time in years). This graph shows the Kaplan–Meier smoothed hazard function computed on the basis of a non-parametric estimation. The analysis time is set in years elapsing since foundation

take into account the influence of possible confounding factors. These are dealt with by the Accelerated Failure Time regression in Sect. 5.2.

5.2 Multivariate results

Table 5 presents the results of the survival analysis, estimated using Eq. (4). Models 1, 3, 5 and 7 show the results of the basic specification, while Models 2, 4, 6 and 8 add other independent variables to control for the possible confounding effects on survival of size, financial performance, entrepreneur characteristics and firm location. We report time ratios (i.e. the exponentiated coefficients of the model) which can be used to compare the effect of our variables on the time to default. A time ratio greater than one means that an increase in that covariates delays the time to default, while the opposite applies for a time ratio lower than one.

Models 1 and 2 investigate the impact of the first requirement (REQ1), related to expenses on R&D. REQ1 is negatively correlated with the survival rates of innovative start-ups, with survival rates between 12 and 13% lower for those firms focusing only on this dimension. In Models 3 and 4 we show the impact of the second requirement, which measures the presence of highly qualified workforce in start-ups' social capital. The impact of this dimension of innovativeness appears positive: start-ups characterized by a high degree of highly qualified workforce show survival rates that are 18–19% higher than their counterparts. Models 5 and 6 show the effect of the output dimension on the survival of innovative start-ups: firms which produce innovation, in terms of patents or licensed software, tend to survive longer. We also note that the impact of REQ3 is even stronger than that of REQ2, with survival rates about 20–25% higher. Finally, Model 7 looks at innovation dummies together: our results seem to suggest that all requirements are important determinants of firm survival. In fact, start-ups with a high spending in R&D show survival

Table 4 Survival rates

Time	Whole sample (%)	REQ1 (%)	REQ2 (%)	REQ3 (%)
1	100.00	100.00	100.00	100.00
2	98.22	97.93	98.66	99.24
3	95.73	95.20	96.51	98.18
4	92.52	91.80	94.04	95.68
5	89.12	87.94	90.65	92.71
Chi2		11.04***	7.21***	32.28***

This table compares the survival rates of different groups of start-ups, clustered on the basis of the three different innovativeness requirements. Chi2 represents the results of the Logrank test for the comparison of each group against the other group. For example, in REQ1 column we show the Logrank test which shows whether statistically significant differences exist between firms which fulfil the first requirement and firms which do not fulfil the first requirement. The variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise

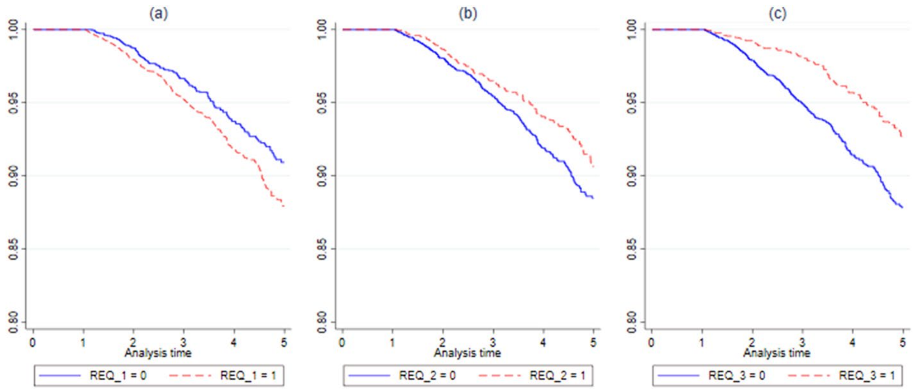

Fig. 2 Kaplan–Meier survival estimates based on different innovation dimensions. Figure 2 shows the KM estimation for the three different innovativeness dimensions considered in this study. Analysis time in years. Panel A shows the estimation for REQ1 (Logrank test $\chi^2 = 11.04$, p-value = 0.00). Panel B shows the estimation for the REQ2 (Logrank test $\chi^2 = 7.21$, p-value = 0.0007). Panel C shows the estimation for REQ3 (Logrank test $\chi^2 = 32.28$, p-value = 0.00)

rates that are about 11% higher, start-ups characterized by highly qualified workforce show survival rates that are about 30% higher, while start-ups characterized by innovation output have an almost 40% higher probability of surviving. Most of these results are confirmed when we add the control variables to Model 8, but in this case the impact of the first requirement is no longer significant, although it is still positive. On the other hand,

Table 5 Results of the Log-normal parametric survival regression

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
REQ1	0.87***	0.88***					1.11*	1.09
	(0.03)	(0.03)					(0.07)	(0.06)
REQ2			1.19***	1.18***			1.32***	1.28***
			(0.05)	(0.05)			(0.08)	(0.07)
REQ3					1.25***	1.20***	1.38***	1.31***
					(0.06)	(0.05)	(0.09)	(0.08)
FEMALE		0.95		0.94		0.95		0.95
		(0.04)		(0.04)		(0.04)		(0.04)
YOUNG		1.00		1.01		1.00		1.01
		(0.05)		(0.05)		(0.05)		(0.05)
FOREIGN		0.78***		0.78***		0.77***		0.78***
		(0.06)		(0.06)		(0.06)		(0.06)
ROA (t-1)		1.00		1.00		1.00		1.00
		(0.00)		(0.00)		(0.00)		(0.00)
SIZE (t-1)		1.10***		1.10***		1.10***		1.10***
		(0.01)		(0.01)		(0.01)		(0.01)
LEVERAGE(t-1)		1.00		1.00		1.00		1.00
		(0.00)		(0.00)		(0.00)		(0.00)
INCUBATOR		1.04		1.03		1.04		1.03
		(0.05)		(0.05)		(0.05)		(0.05)
Constant	10.33***	6.74***	9.13***	5.97***	9.084***	6.08***	8.12***	5.51***
	(3.20)	(1.88)	(2.83)	(1.68)	(2.80)	(1.71)	(2.55)	(1.57)
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
chi2	1763.32***	1613.59***	1749.55***	1607.46***	1755.13***	1591.97***	1753.57***	1590.90***

Table 5 (continued)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
ll	−1369.43	−1327.93	−1367.56	−1325.58	−1365.00	−1325.24	−1353.25	−1313.55
AIC	2810.87	2741.86	2807.12	2737.16	2802.00	2736.48	2782.51	2717.10
BIC	3100.75	3088.11	3097.01	3083.41	3091.89	3082.73	3088.50	3079.46
N	23,210	23,210	23,210	23,210	23,210	23,210	23,210	23,210

Table 5 presents the results of the lognormal model, estimated using Eq. (4). We report time ratios, i.e. the exponentiated coefficients of the model. Continuous variables are lagged by 1 year. All models include region, sector and year fixed effects. Robust standard errors are clustered at firm level, in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise

Table 6 Results of the Log-normal parametric regression with interactions between the innovation variables

	Model 9	Model 10	Model 11	Model 12
REQ1	0.82***	0.88***		0.51**
	(0.04)	(0.04)		(0.17)
REQ2	0.94		1.21***	0.59
	(0.06)		(0.05)	(0.19)
REQ3		1.06	1.24***	0.63
		(0.06)	(0.06)	(0.21)
REQ1 X REQ2	1.61***			2.57***
	(0.18)			(0.91)
REQ1 X REQ3		1.27**		2.08**
		(0.13)		(0.72)
REQ2 X REQ3			0.98	1.82
			(0.12)	(0.67)
REQ1 X REQ2 X REQ3				0.44*
				(0.19)
WOMEN	0.94	0.95	0.95	0.94
	(0.04)	(0.04)	(0.04)	(0.04)
YOUNG	1.01	1.01	1.01	1.00
	(0.05)	(0.05)	(0.05)	(0.05)
FOREIGN	0.78***	0.78***	0.78***	0.77***
	(0.06)	(0.06)	(0.06)	(0.06)
ROA(t-1)	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
SIZE(t-1)	1.10***	1.10***	1.10***	1.10***
	(0.01)	(0.01)	(0.01)	(0.01)
LEVERAGE(t-1)	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
INCUBATOR	1.03	1.03	1.03	1.02
	(0.05)	(0.05)	(0.05)	(0.05)
Constant	7.23***	6.78***	5.95***	11.64***
	(2.05)	(1.90)	(1.67)	(5.05)
Sector FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
chi2	1,615.67***	1598.54***	1602.14***	1604.39***
ll	− 1313.91	− 1320.67	− 1314.66	− 1308.91
AIC	2717.82	2731.34	2719.32	2715.81
BIC	3080.18	3093.69	3081.68	3110.38
N	23,210	23,210	23,210	23,210

Table 6 presents the results of the lognormal model, estimated using Eq. (4). We report time ratios, i.e. the exponentiated coefficients of the model. Continuous variables are lagged by 1 year. All models include region, sector and year fixed effects. Robust standard errors are clustered at firm level, in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of

Table 6 (continued)

the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise

the focus on skilled employees/founders and on output increases survival rates by 28% and 31% respectively.

As far as the control variables are concerned, the results are consistent across the different models. With regard to entrepreneur demographics, female-led and young-led start-ups do not show statistically different survival rates compared to their counterparts, while firms led by foreign-born entrepreneurs fail at a rate about 22–23% higher. This is consistent with a part of literature that states that foreign firms tend to show a "liability of foreignness" (Zaheer, 1995). Looking at the intrinsic characteristics of the firms, profitability and size are positively correlated with survival, consistently with the literature that finds that bigger firms tend to survive longer (Ferrucci et al., 2021; Ugur et al., 2016). Moreover, we do not find any appreciable effect of profitability and leverage. With regards to the INCUBATOR variable we do not find any significant result.

However, results shown in Table 5 may not show the entire picture of the effect of innovation on the survival of innovative start-ups. In fact, start-ups have to comply with at least one of the innovation requirements, but each start-up may meet more than one requirement. It is therefore important to investigate whether in firms where different innovation dimensions coexist, their possible interaction affects firm survivability. In Table 6 the main models now include interactions between the innovativeness requirements. Model 9 shows that, while the effect of the expenses on R&D is still negative, when interacted with REQ2, the joint impact becomes positive: start-ups meeting both requirements have, on average, survival rates about 51% and 32% higher than start-ups meeting only either the first or the second requirements respectively.[20] In Model 10, the first requirement is interacted with the third one, and while the impact of REQ1 alone is negative, when both dimensions are present simultaneously, the resulting impact is positive: a firm meeting both the requirements has an average survival rate which is 34% or 11% higher than a start-up meeting only the first or the third requirement, respectively. Model 11 shows how REQ2 and REQ3 interact. The interaction is not significant, but the positive impact of the individual dimensions is still statistically and "economically" significant, as also shown in Table 5. Finally, results of Model 12 show the fully interacted model. From this model we can compute the differential in average survival rates between firms which meet all three requirements and

[20] These values are obtained by using the predicted values for the coefficients, in logarithms, and comparing each time two firms which differ only by the requirement fulfilled: the value obtained from this subtraction is then exponentiated again to obtain the average predicted differential survival rate. Since the requirements are not mutually exclusive, we need to compare a firm having the two requirements with both a firm only having the first requirement and a firm only having the second requirement. In the rest of the paper, when we write about the effect of the interaction we refer to this particular computation. We thank an anonymous reviewer for the insightful comment on the interpretation of the interactions.

firms with one or two requirements. Comparing the survival rates with a firm meeting only REQ1, a firm meeting all three requirements has an increased survival chance of about 59%; similar reasoning can be followed for the other requirements. We can also make a comparison with start-ups meeting two out of three requirements. In particular, for a firm meeting both REQ1 and REQ2, the difference is significantly smaller, with a shortfall of about 4.9% compared to the average start-up meeting all three requirements. Again, the results are qualitatively similar in making a comparison with the other pairs of requirements. Overall, these results show how the impact of the three innovativeness dimensions is bigger when these dimensions are present together in the same firm, especially when the R&D requirement is met alongside the other two.

Finally, with regards to the control variables, results remain qualitatively similar: female and young entrepreneurs do not show statistically different survival rates, while foreign-born entrepreneurs are affected by the "liability of foreignness" noted above. Bigger firms tend to survive longer, and finally, the results on the presence of incubators/science parks are confirmed.

5.3 Robustness checks

Endogeneity produced by treatment selection bias occurs when observations are non-randomly sorted into different discrete groups (Lennox et al., 2012). This is a common problem in non-experimental settings like this one. In fact, we note that it is the entrepreneurs themselves who shape how their firms will operate (Del Bosco et al., 2021; Hashai & Zahra, 2022). This, in turn, will determine which of the three legal requirements is met when the firm is formally registered as an innovative start-up. The type of innovation requirement followed by each start-up can therefore be considered as internally chosen, and this is what causes the treatment selection bias. One of the most common approaches to overcome this type of bias is the Heckman two-step selection model (Heckman, 1979; Robson et al., 2012). This consists of estimating two separate regression models. In the first step we run a probit model to determine the probability of focusing on a specific type of requirement. Three different probit regressions, one for each innovativeness requirement, are run. The dependent variable is a dummy equal to 1 if the start-up fulfils a specific requirement, and 0 otherwise. The probit models are estimated as follows:

$$Prob\left(Req_{i,t} = 1|X_{i,t}\right) = \Phi\left(\alpha + \sum_{k=1}^{K} \beta_k X_{k,i,t} + \beta_{K+1} GREEN_i + u_{it}\right) \quad (5)$$

where X_{kit} is the vector containing the same variables used in Eq. (4) with the exception of the requirements variables, α is a constant term, and Φ is the standard normal cumulative distribution function. GREEN is a dummy variable equal to 1 if the start-up is defined as a "high technological value company in energy related fields" as per Italian regulations on innovative start-ups (Serio et al., 2020). Choosing GREEN as our exclusion restriction can be justified theoretically. As Barbieri et al. (2020) demonstrate, green technologies tend to be "newer" and more complex, indicating that green technology tends to be more innovative, so the propensity of the management towards sustainability fosters radical, rather than incremental, innovation (Shu et al, 2016). In this regard, we can say that the green dynamic capabilities of the entrepreneurs enhance innovation efforts of firms (Amui et al., 2017), thus leading to a situation in which start-ups, which are usually modelled after the founders, are more innovative when the entrepreneur has strong environmental awareness.

However, as a recent study by Leoncini et al. (2019) showed, younger firms do not reap the benefit of green innovation as well as older firms do. Therefore, we posit that our exclusionary restriction, GREEN, will have an impact on the innovativeness propensity of innovative start-ups but not on their survival. We also include the squared values of the continuous variables because it can greatly decrease the treatment selection bias (Caselli et al., 2021). The results of the probit regressions are reported in Appendix C.

The results of the first stage are then used to construct the Inverse Mills Ratio (MILLS) for each firm-year observation as follows:

$$MILLS_{it} = \frac{\varphi(Z_{it}\widehat{Y})}{1 - \Phi(Z_{it}\widehat{Y})} \tag{6}$$

where φ() and Φ() represent, respectively, the probability density function and the cumulative distribution function of a standard normal distribution, and $Z_{it}\widehat{Y}$ denotes the estimated probability of fulfilling a specific innovation requirement. This new variable is then added to the main model represented in Eq. (4) in the second step, in which we control for treatment selection bias. Certo et al. (2016) highlight how two conditions are necessary for selection bias to be present. First, the exclusion restriction must be a significant predictor in the first stage: Appendix C in fact shows that the variable GREEN is a significant predictor in all three probit regressions. Second, there must be a significant, even if small, correlation between the residuals of the Eq. (5) and Eq. (4) with MILLS as a covariate: in Table 7, we show that the correlation values, indicated as *rho*, are significant in all models except for the first requirement. Therefore, treatment selection bias is present in our sample, and we report the results of the main regression while controlling for the selection bias in Tables 7 and 8.

Table 7 reports the results of the Log-normal models with the addition of the Inverse Mills Ratio as a covariate. Even after controlling for the treatment selection bias, we note that most of our results are confirmed. We can see that, when considered alone, REQ1 is negatively correlated to the survival rates of innovative start-ups. However, when all the innovativeness requirements are considered, the impact of REQ1 becomes less clear. On the other hand, a highly skilled workforce and an innovative output appear to be significant determinant of start-up survival. Of the two, the innovative output seems to be a stronger determinant of survival: start-ups focusing on a skilled workforce have survival rates 17–28% higher, while start-ups focusing on the output show survival rates which are 21–32% higher. With regards to the control variables, the impact of the entrepreneur changes slightly. The effect of young entrepreneurs is still non-significant, but the negative impact of foreign start-uppers appears to be weaker after controlling for selection bias. We also find evidence that women-led start-ups tend to show lower survival rates. Moreover, bigger firms are again found to survive longer.

Table 8 presents the results of the interaction between innovativeness variables while controlling for treatment selection bias. As before, Model 17 shows that the impact of R&D expenses alone is significant and negative: start-ups focusing only on this dimension show a lower survival rate. However, when a skilled workforce is present alongside the input dimension, the resulting effect is positive: firms focusing on both dimensions have a lower average failure rate. A similar positive effect can be seen in Model 18. While the input dimension alone has a negative impact on the survivability, when it is supported by an innovative output, the overall effect is positive. Moreover, Model 19 shows that REQ2 and REQ3 alone both tend to have a positive effect on the survival of innovative start-ups, while the interaction between them is not significant. Finally, Models 19 and 20 also reveal strong complementarities between R&D expenses and the other two dimensions of innovativeness. Also, the joint effect of having all three requirements appears to be negative, even if the significance of the relationship is weak.

Finally, there is a need to find out how survival rates of start-ups changed during the Covid-19 pandemic. Table 9 thus includes a dummy variable equal to 1 for the years 2020 and 2021. The results show that, in general, during the pandemic, survival rates indeed changed, and decreased by 10% on average, while we also find that the effect was slightly counteracted by the innovativeness requirement related to R&D expenses. While we cannot infer a strong moderating effect of innovativeness on the impact of the pandemic on firm survival, we can conclude that it enhanced start-up survival during the pandemic too.

6 Discussion and conclusions

The innovation process is a key aspect of the everyday life of an entrepreneur, since firms that do not innovate tend to stagnate and, eventually, exit from the market (Kahn, 2018; Meissner & Kotsemir, 2016). Starting from this general consideration, the literature highlights how there is still a need to understand how innovation and innovation capabilities come into play in the survival game of young entrepreneurial firms (Fiorentino et al., 2021; Ugur & Vivarelli, 2021; Zhang & Mohnen, 2022). As suggested by Rosenbusch et al. (2011), this relationship might be context-dependent because many factors affecting firm survival are intertwined with the innovation process. This could explain how different ways of measuring the innovativeness of start-ups lead to differential, and sometimes even contradicting, results (Dziallas & Blind, 2019). This study tries to shed light on this issue by investigating whether different measures of innovativeness (i.e., those laid down by the Italian Government through the Startup Act) have a different effect on innovative start-up survival rates. We analyse a sample of 9171 innovative start-ups, by applying survival analysis methodology, also known as *duration analysis*, a common methodological framework in the biomedical field (George et al., 2014), recently adopted in entrepreneurship literature to investigate the causes of survival of SMEs (e.g., Ugur & Vivarelli, 2021). Both a non-parametric approach (Kaplan–Meier curves), and a fully parametric approach (Accelerated Failure Time models) are followed.

We find that, in general, innovative capabilities have a positive impact on the survival of new ventures, although this finding requires some important clarifications. Our results show that, when considered alone, the first requirement (R&D expenses of a start-up equal to or greater than 15% of the higher value of either total costs or total revenues) does not seem to have a clear impact on the survival rates of innovative firms. This is probably a reflection of how the innovation process is organized and how it can lead to the actual generation of innovative outputs. The first requirement is, in fact, a purely accounting requirement and does not take account of how the R&D expenditure is to be used. There are two aspects of the spending behaviour of this kind of firm that should be considered. First, regulatory policies tend to require start-ups to focus their spending on R&D processes to obtain funds, thus supporting the supply side (Guerrero & Urbano, 2019). Second, due to their size and operational characteristics, it is easier for start-ups to allocate proportionally more resources to R&D. The very nature of these firms requires them to spend more on areas that could generate innovation, such as R&D. On this point, Hansen (1992) highlights how small firms may not be able to report costs related to innovation separately from costs related to other functions. This leads to an underreporting of R&D expenditure

Table 7 Results of the Log-normal parametric survival regression controlling for treatment selection bias

	Model 13	Model 14	Model 15	Model 16
REQ1	0.88***			1.09
	(0.03)			(0.06)
MILLS_1	1.66			3.87
	(0.83)			(4.23)
REQ2		1.17***		1.28***
		(0.05)		(0.07)
MILLS_2		2.19*		6.35***
		(0.89)		(4.60)
REQ3			1.21***	1.32***
			(0.05)	(0.08)
MILLS_3			0.25***	0.37
			(0.10)	(0.28)
WOMEN	0.96	0.91*	0.94	0.91*
	(0.05)	(0.04)	(0.04)	(0.05)
YOUNG	0.95	1.06	0.94	0.94
	(0.08)	(0.06)	(0.05)	(0.09)
FOREIGN	0.74***	0.87	0.78***	0.88
	(0.07)	(0.09)	(0.06)	(0.10)
ROA(t-1)	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
SIZE(t-1)	1.09***	1.13***	1.14***	1.17***
	(0.01)	(0.02)	(0.02)	(0.04)
LEVERAGE(t-1)	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
INCUBATOR	1.02	1.00	0.98	0.89*
	(0.05)	(0.05)	(0.05)	(0.05)
Constant	4.13**	3.72***	7.41***	0.54
	(2.32)	(1.34)	(2.09)	(0.81)
Sector FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
chi2	1653.46***	1625.96***	1643.81***	1631.78***
ll	− 1327.45	− 1323.96	− 1320.60	− 1304.92
AIC	2742.91	2735.92	2729.21	2705.84
BIC	3097.21	3090.22	3083.50	3092.34
N	23,210	23,209	23,205	23,204
rho	− 0.01	0.015**	0.017**	–
rho_REQ1	–	–	–	− 0.008
rho_REQ2	–	–	–	0.015**
rho_REQ3	–	–	–	0.016**

Table 7 presents the results of the lognormal model, estimated using Eq. (4), to which the inverse Mills ratio is added as a covariate to control for treatment selection bias. We report time ratios, i.e. the exponentiated coefficients of the model. Continuous variables are lagged by 1 year. All models include region, sector and year fixed effects. Robust standard errors are clustered at firm level, in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively. The independent variables are as follows: REQ1 is rep-

Table 7 (continued)

resented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise; MILLS indicates the inverse mills ratio obtained with Eq. 6

(Kleinknecht, 1987), and may also partially explain the unclear relationship found between REQ1 and survival. On the other hand, the same evidence shown by Hansen (1992) can lead, in the case of Italian innovative start-ups, to the opposite scenario, where entrepreneurs purposely over-report R&D expenditure in order to reap legislative benefits of the status of innovative start-up, which might also explain the puzzling results relating to REQ1.

We also find that a skilled workforce and producing an actual innovative outputs have a positive impact on start-up survival, with the second having a stronger effect. Therefore, young firms benefit more from an orientation in innovation that actually and effectively produces innovative outputs than from simply pouring more and more resources into R&D. This pattern is related to the fact that new products or registered IP are perhaps a more direct measure of innovations carried out by start-ups, and may thus yield a sort of "innovation premium" that enhances their survival chances. This innovation premium can also be explained in evolutionary terms: output measures reflect a firm's success in converting R&D investment into concrete innovation results (Ugur & Vivarelli, 2021). This, in turn, brings greater market power, which helps innovating firms to survive. In a virtuous cycle, start-ups which effectively innovate are those which grow more and, hence, have a better chance of surviving. In fact, output measures usually highlight a firm's success in transforming an innovation cost into an innovation outcome. And as reported in the literature, the innovation output of firms has a marginal effect on survival greater than inputs, perhaps because the latter are typically subject to uncertainties and unpredictable returns (Scherer & Harhoff, 2000).

These results are also in line with the framework of Italian legislation. Indeed, the first requirement for being considered an innovative start-up according to Italian legislation is expressed in accounting terms, and does not reflect how and when R&D expenditure is used or what it yields. The other two requirements are more closely linked to the ability of firms to produce and commercialize innovation, which is related to the actual competitive advantages of start-ups in market survival. In fact, the descriptive statistics in Sect. 4.1 show that about 60% of start-ups meet the first requirement, and only about 25–30% meet the other two.

However, we also find that when the first requirement is met alongside the other two dimensions, the relationship becomes positive. As highlighted by Mohnen and Hall (2013), there appear to be complementarities between different aspects of the innovation process. These results might also shed light on the unclear effect of meeting the first requirement. If

Table 8 The effect of the interactions while controlling for treatment selection bias

	Model 17	Model 18	Model 19	Model 20
REQ1	0.82***	0.88***		0.51**
	(0.04)	(0.04)		(0.17)
REQ2	0.94		1.21***	0.59
	(0.06)		(0.05)	(0.20)
REQ3		1.07	1.25***	0.63
		(0.06)	(0.06)	(0.21)
REQ1 X REQ2	1.60***			2.54***
	(0.18)			(0.89)
REQ1 X REQ3		1.27**		2.09**
		(0.13)		(0.72)
REQ2 X REQ3			0.98	1.84*
			(0.12)	(0.67)
REQ1 X REQ2 X REQ3				0.44*
				(0.18)
MILLS_1	9.45***	0.48		4.05
	(5.83)	(0.32)		(4.42)
MILLS_2	8.05***		3.28**	6.43***
	(4.51)		(1.90)	(4.65)
MILLS_3		0.16***	0.19***	0.39
		(0.09)	(0.08)	(0.30)
WOMEN	0.93	0.91*	0.89**	0.91*
	(0.05)	(0.05)	(0.05)	(0.05)
YOUNG	0.89	1.01	1.02	0.93
	(0.07)	(0.09)	(0.06)	(0.09)
FOREIGN	0.83*	0.85	0.93	0.87
	(0.09)	(0.09)	(0.10)	(0.11)
ROA(t-1)	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
SIZE(t-1)	1.13***	1.17***	1.19***	1.17***
	(0.02)	(0.03)	(0.03)	(0.04)
LEVERAGE(t-1)	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
INCUBATOR	0.90*	0.98	0.92	0.89*
	(0.05)	(0.05)	(0.05)	(0.05)
Constant	0.23*	17.98***	3.61***	1.08
	(0.20)	(13.50)	(1.58)	(1.63)
Sector FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
chi2	1651.23***	1665.41***	1635.89***	1632.18***
ll	− 1307.36	− 1315.22	− 1306.76	− 1304.79
AIC	2708.72	2724.44	2707.53	2707.58
BIC	3087.18	3102.89	3085.98	3102.13
N	23,209	2,3205	23,204	23,204

Table 8 (continued)

Table 8 presents the results of the lognormal model, estimated using Eq. (4), to which the inverse Mills ratio is added as a covariate to control for treatment selection bias. We report time ratios, i.e. the exponentiated coefficients of the model. Continuous variables are lagged by 1 year. All models include region, sector and year fixed effects. Robust standard errors are clustered at firm level, in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise; MILLS indicates the inverse mills ration obtained with Eq. 6

start-ups are making actual innovation, then their R&D expenditure should be well directed towards remunerative investments, either in skilled employees or innovative products, and they would not feel the need to adjust their financials in order to artificially meet the first requirement of the Startup Act. This research gives some additional insight into the existence of these interactions: when strong R&D expenses are supported by a skilled workforce which can actually and effectively create innovative outputs, the effects of high R&D spending changes from negative to positive. These findings provide evidence that the complementarities between different measures of innovativeness can also benefit young innovative firms. The innovation process should thus be oriented towards the actual production of innovative outcomes, and it also follows that it is the "productivity of innovation" that should be considered when investigating the relationship between innovativeness and start-ups' survival. Therefore, spending more resources on R&D becomes even more important when a firm has the internal capabilities to fully exploit these additional resources to produce an effective innovation.

In short, the contribution of this study is twofold and consists of showing: (i) how different measures of innovativeness produce different effects on the survival of innovative start-ups, and (ii) that complementarities between different measures should also be considered, because they can provide additional benefits in terms of business performance.

These results have some important policy implications. Start-ups are doomed to fail early if they are not driven by strong innovation drivers (Cefis & Marsili, 2006). As long as the effect of R&D investment on firm survival is indeterminate and depends on the stochastic outcomes of the investment and the competitive pressure from outside the industry (Ericson & Pakes, 1995), these findings should encourage policymakers to identify and support drivers which enhance innovation capabilities of entrepreneurs. This could mean enhancing university-firm collaboration or creating science parks for the development of innovative products and services, rather than just simply providing tax exemptions for firms spending more on R&D without considering what the spending yields. Such measures would create an innovative ecosystem fostering the survival and growth of innovative firms, and help bring about Schumpeter's creative destruction that ultimately leads to economic and social growth.

Table 9 The changes in survival rates in the years of the Covid-19 pandemic

	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26	Model 27
COVID	0.92**	0.91**	0.92**	0.80***	0.94	0.94	0.83
	(0.04)	(0.04)	(0.04)	(0.06)	(0.04)	(0.04)	(0.12)
REQ1	0.89***			0.77***			1.01
	(0.04)			(0.05)			(0.12)
REQ2		1.19***			1.33***		1.38***
		(0.05)			(0.11)		(0.17)
REQ3			1.20***			1.30***	1.36**
			(0.06)			(0.11)	(0.17)
REQ1 X COVID				1.23**			1.18
				(0.10)			(0.17)
REQ2 X COVID					0.85*		0.94
					(0.08)		(0.13)
REQ3 X COVID						0.89	0.97
						(0.09)	(0.14)
WOMEN	0.95	0.94	0.95	0.95	0.94	0.95	0.95
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
YOUNG	1.04	1.04	1.03	1.04	1.04	1.03	1.04
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
FOREIGN	0.77***	0.78***	0.77***	0.77***	0.77***	0.77***	0.77***
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
ROA(t-1)	1.00*	1.00*	1.00**	1.00*	1.00*	1.00**	1.00*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
SIZE(t-1)	1.11***	1.11***	1.10***	1.11***	1.11***	1.10***	1.10***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
LEVERAGE(t-1)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
INCUBATOR	1.03	1.02	1.04	1.03	1.02	1.04	1.02
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Constant	7.85***	6.91***	7.18***	8.67***	6.77***	7.06***	6.42***
	(2.07)	(1.84)	(1.91)	(2.34)	(1.80)	(1.88)	(1.87)
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No	No	No
chi2	1685.28***	1763.56***	1496.51***	1633.80***	1724.10***	1502.18***	1666.60***
ll	− 1654.23	− 1650.41	− 1651.12	− 1651.60	− 1649.13	− 1650.61	− 1636.78
AIC	3386.45	3378.82	3380.25	3383.20	3378.27	3381.23	3361.56
BIC	3700.49	3692.86	3694.29	3705.29	3700.36	3703.32	3715.86
N	23,210	23,210	23,210	23,210	23,210	23,210	23,210

Table 9 presents the results of the lognormal model, estimated using Eq. (4), to which a dummy variable, COVID, is added to assess the effect the Covid-19 pandemic on the survival of innovative start-ups. We report time ratios, i.e. the exponentiated coefficients of the model. Continuous variables are lagged by 1 year. All models include region and sector fixed effects. Robust standard errors are clustered at firm level, in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN

Table 9 (continued)

is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise; COVID is a dummy variable equal to 1 for the years 2020 and 2021, and 0 otherwise

Moreover, regarding entrepreneurs themselves, there is a clear indication that firm success is driven by the creation of competitive advantage over competitors and, also, incumbent firms (Moroni et al., 2015). However, these competitive advantages depend on the ability of firms to actually implement and adopt technological innovations (Günsel, 2015), which in the case of young firms, depends closely on the intrinsic knowledge of entrepreneurs and human capital (Audretsch et al., 2014; Grimpe & Hussinger, 2013). This means that entrepreneurs should also focus on developing their own specific innovative *forma mentis* of considering the entire innovation process as a whole and thus creating the conditions for actual and effective innovation (Wang & Ahmed, 2004). Building on this, entrepreneurs will have a clear path towards the introduction of competitive advantages for their firms which could facilitate their survival.

Our findings may also be useful to incentivize policy makers to encourage start-ups' access to external credit, including bank credit. In fact, although the financing of innovation is an important aspect of promoting economic growth, innovative firms often turn out to be financially constrained, essentially for two reasons. The first is information asymmetry, as potential financiers may struggle to evaluate potential success due to a lack of information, which companies are reluctant to provide partly because of the risk of imitation. The second reason for financial constraint is that innovative firms often have a high level of intangible assets that cannot be pledged as collateral (Ferrucci et al., 2021). Partly for this reason, the European Commission supports access to funding for businesses through local financial institutions in EU countries,[21] willing to offer lower interest rates, larger financing volumes or smaller collateral requirements. Many types of funding can be envisaged, including loans, microfinance and guarantees or equity funding through venture capital funds, business angels or social investors. Indeed, our results also offer implications for private equity practitioners: since venture capitalist are found to be the major backers of new ventures (Kortum & Lerner, 2000), they should pay attention to who produces actual innovation, because, in the case of the production of innovation, it is the "how" and not the "how much" that leads to survival and, ultimately, to the success of entrepreneurial firms.

This study, like others in the innovation literature, has some limitations. First, since we retrieved the list of innovative start-ups at a single point in time, we only have a static representation of the entire population of this kind of firms and their characteristics. This could affect our results in two ways. On the one hand, although the AIDA database keeps all the records of firms even after they have gone bankrupt, we could have missed some of the firms due to the match with data from the special section of innovative start-ups. This

[21] See https://commission.europa.eu/business-economy-euro/growth-and-investment/financing-investment/financing-programmes-smes_en#:~:text=Financing%20programmes-,How%20it%20works,business%20angels%20or%20social%20investors.

means we could not perform the analysis on firms which failed before we accessed the database on April 2022, thus leading to an attrition bias. Unfortunately, to date (November 2023), it is still not possible to retrieve historical data about innovative start-ups from the Italian Company Register: having this data may probably reveal how serious the problem of attrition is and would enable the issue to be addressed, as done, for example, in Bolzani et al. (2021). The fact that we do not have access to historical data may also have driven the results for REQ1. Innovative start-ups are required by the Startup Law to update, at least once a year, their data with regards to the fulfilment of the requirements. Static representation does not show whether and how these firms evolve in terms of innovativeness requirements: a start-up meeting only the first requirement, for example, would produce a patented product some years after the initial investment.[22] Since innovation is a complex and dynamic phenomenon, we need to be aware that part of our results may be driven by the fact that we cannot observe the evolution of the life of these firms within the innovative start-ups framework. Moreover, because of the absence of data in the AIDA database, firms set up after 2020 were discarded from the original sample, whereas, as shown in Appendix D, most observables are different between firms set up before and after 2020. Even though this probably affects the generalization of our results, which are robust only in a static sense, we need to be aware that start-ups founded after 2020 were set up in a context which was fundamentally altered by Covid-19, and the effects of the pandemic on the entrepreneurial process are still mostly unclear. Further studies are necessary to confirm our results by enlarging the dataset to post-2020 firms too. Unfortunately, at present, it is not possible to retrieve the register of Italian innovative start-ups in different points in time and a dynamic investigation of the effect of different innovativeness requirements is thus not feasible on this particular dataset.

Second, the innovativeness measures we use are defined by the government. These may be an objective indicator of innovativeness, but only as far as the government can be considered an effective judge of the innovation process. As noted above, the first requirement set by the Startup Act is based purely on an accounting basis and may not capture actual expenditure on R&D, so as suggested by Dziallas and Blind (2019), our results are also subject to a certain degree of subjectivity. The Startup Law also neglects another important aspect, contextual innovation, i.e. the innovation related to the environment in which a firm operates. Therefore, our study suffers from the fact that our innovativeness measures are qualitative in nature and do not consider the entire spectrum of the phenomenon of innovation.

Third, because we need to define a point in time in which a firm stopped, de facto, its operations, we define survival as the time from the foundation of the firm until the year after the last annual report. But it is known that the bankruptcy process can take years from beginning to end (Balcaen & Ooghe, 2006) which implies that our dataset could be showing firms unofficially not operational but still registered as active. To prevent this from causing bias in our results, we opted for the above definition of our main construct, although it is not the only one used in the literature (Balcaen & Ooghe, 2006). It is the case that different definitions of failure might give different results on the impact of

[22] This might also explain why we find a negative correlation between the three requirements. In fact, as also highlighted in Ministero dello Sviluppo Economico (2022), most of the innovative start-ups declare that they meet only one of the three requirements: the negative correlation is, thus, a result of the fact that the three requirements are rarely found together in a single firm. A dynamic representation of the list of innovative start-ups may indicate that the relationship is in fact positive.

innovativeness on firms' survival. Moreover, this operationalization entails that firms for which data are missing in the AIDA database are discarded from our sample, and since these comprise about 35% of the initial dataset, we need to be cautious about the generalization of our findings. Further analyses are required to confirm our results.

Fourth, start-ups registered in the special section of the Italian Company Register are classified as being characterized by innovativeness, but this does not mean that firms not appearing in the section are not innovating too. It would also be interesting to discover whether and how the innovativeness of these two types of firm differs.

The limitations of our study, however, can pave the way for future research. In fact, as discussed, the static nature of our data retrieval process may have driven part of our results, both in terms of attrition bias and in terms of the how the innovation process unfolds in a firm. An analysis that could access all these kinds of information related to the composition of the innovative start-ups' ecosystem would address this particular bias and indicate how the evolution of the innovativeness of the entrepreneurial firms influence its survival. We used innovativeness measures which are policy-designed and set by law, but as noted above, regulators may not be the most competent judges of the innovation process. Further research might, thus, investigate whether the legislative requirements capture the innovation process as a whole. This could be done, for example, by comparing these measures with more traditional indicators of innovation, as described by Dziallas and Blind (2019). Finally, there is a need to identify the influence of institutional investors, venture capitalists and, particularly, private equity firms, in the survival of entrepreneurial firms. This kind of investor are fundamental for the support of innovative ecosystems, since more traditional lenders are typically less attracted to firms like start-ups which do not have a proven track record (Fulghieri & Sevilir, 2009). In exchange for their financial support, however, venture capitalists tend to exert a considerable influence on the operations of firms they back, especially with regards to the innovation process (Rossi et al., 2022). Because our study shows that innovativeness is a strong predictor of start-up survival, future research could usefully explore whether venture capitalists should be considered as mediators or moderators of the relationship between innovativeness and entrepreneurial firm failure.

Overall, this study contributes to the literature on the relationship between innovation and entrepreneurial firms. In particular, we investigate how different innovation measures yield differential impacts on innovative start-up survival. The empirical results show how the resources spent on the R&D process need to be backed by internal capabilities for the resources to be fully exploited, and by clear objectives for effective innovation to be actually produced. The study highlights how important complementarities exist between the various measures of innovation and how these can significantly affect the survival rates of innovative firms.

Appendix A

See Table 10.

Table 10 Summary of studies

Authors, Year	Title	Main results
Panel A: Main determinants of firm survival, including innovation		
Audretsch (1991)	New-firm survival and the technological regime	Firm size is an important determinant because the ability to attract financial capital increases with it.
Persson (2004)	The Survival and Growth of New Establishments in Sweden, 1987–1995	Firm survival increases with age, size of the firm, and the educational attainment of the employer and entrepreneurial team.
Bolzani et al. (2019)	Entrepreneurial Teams: An Input-Process-Outcome Framework	
Esteve-Pérez et al. (2018)	Age and productivity as determinants of firm survival over the industrial life cycle	Age and productivity play a different role in firm survival across three stages of the life cycle ('early', 'mature' and 'intermediate' stage).
Boyer and Blazy (2014)	Born to be alive? The survival of innovative and non-innovative French micro-start-ups	Variables related to human capital or personal characteristics positively affect the survival of innovative companies.
Strotmann, 2007	Entrepreneurial Survival	Sector-specific conditions are conducive to firm survival.
Buehler et al. (2012)	The geographic determinants of bankruptcy: evidence from Switzerland	Firm entry and exit were more closely associated with regional economic conditions.
Keeble and Walker (1994)	New firms, small firms and dead firms: Spatial patterns and determinants in the United Kingdom	
Renolds et al. (1994)	Cross-national comparisons of the variation in new firm formation rates	
Renski, 2011	External economies of localization, urbanization and industrial diversity and new firm survival	
Acs et al. (2007)	The determinants of new-firm survival across regional economies	In the service sector, there is a negative relationship between the high school dropout rate and firm survival.
Aghion and Howitt (1998)	Capital Accumulation and Innovation as Complementary Factors in Long-Run Growth	Innovation affects firm survival.
Aghion et al. (2015)	Lessons from Schumpeterian Growth Theory	
Klette and Kortum (2004)	Innovating Firms and Aggregate Innovation	

Table 10 (continued)

Authors, Year	Title	Main results
Ghura et al. (2022)	Corporate entrepreneurship champions: mapping the past and present states of the field for future advancements	Innovation is a key issue for SMEs.
Innocenti and Zampi (2019)	What does a start-up need to grow? An empirical approach for Italian innovative start-ups	Innovation is a key issue for start-ups.
Geroski et al. (1993)	The Profitability of Innovating Firms	Innovation reduces the sensitivity of start-ups to adverse macroeconomic shocks, thus representing a driver of their growth.
Geroski et al. (1997)	How persistently do firms innovate?	
Cefis and Ciccarelli (2005)	Profit differentials and innovation	Innovative firms have competencies and behavioural patterns that enable them to weather economic shocks and market challenges.
Ahmed et al. (2020)	Steering firm performance through innovative capabilities: A contingency approach to innovation management	Process and product innovation complement each other for improving innovation speed and quality.
Song et al. (2007)	Success Factors in New Ventures: A Meta-analysis	Innovation has a positive impact on the survival of businesses.
Banbury and Mitchell (1995)	The effect of introducing important incremental innovations on market share and business survival	Innovation is an important competitive factor.
Nelson and Winter (1982)	The Schumpeterian Tradeoff Revisited	
Porter (1980)	Competitive Strategy: Techniques for Analyzing Industries and Competitors	
Shoham, Fiegenbaum (2002)	Competitive determinants of organizational risk-taking attitude: the role of strategic reference points	
Zahra and George (2002)	Absorptive Capacity: A Review, Reconceptualization, and Extension	Innovation affects absorptive capacity.
Eisenhardt, Martin (2000)	Dynamic capabilities: what are they?	Innovation contributes to improving dynamic capabilities.
Teece et al. (1997)	Dynamic capabilities and strategic management	

Table 10 (continued)

Authors, Year	Title	Main results
Cohen and Klepper (1996)	Firm Size and the Nature of Innovation within Industries: The Case of Process and Product R&D	Innovation can contribute to reducing costs.
Zhang et al. (2020)	Firm dynamics of hi-tech start-ups: Does innovation matter?	Innovation creates value for SMEs.
Hall et al. (2008)	Employment, innovation, and productivity: evidence from Italian microdata	Innovation contributes to employment growth.
Arrighetti and Vivarelli (1999)	The role of innovation in the post entry performance of new small firms	Innovation has a positive effect on start-ups' survival rates.
Audretsch (1995)	Firm Profitability, Growth, and Innovation	
Cefis and Marsili (2006)	Survivor: The role of innovation in firms' survival	
Colombelli et al. (2016)	To be born is not enough: the key role of innovative start-ups	
Helmers and Rogers (2010)	Innovation and the Survival of New Firms in the UK	
Cefis and Marsili (2005)	A matter of life and death: innovation and firm survival	The level of impact of the innovation varies according to whether it is a product or a process innovation and according to its degree.
Saemundsson and Dahlstrand (2005)	How Business Opportunities Constrain Young Technology-Based Firms from Growing into Medium-Sized Firms	
Buddelmeyer et al. (2010)	Innovation and the determinants of company survival	In the case of a major innovation, being innovative becomes a negative factor for the survival of SMEs.
Ram and Jung (1991)	"Forced" adoption of innovations in organizations: Consequences and implications	Innovation does not always have a beneficial impact on companies because of resistance to innovation.
Berggren and Nacher (2001)	Introducing new products can be hazardous to your company: Use the right new-solutions delivery tools	Innovation does not always have a beneficial impact on companies because of failure of innovation.
Damanpour, 1991	Organizational Innovation: A Meta-Analysis Of Effects Of Determinants and Moderators	
Hultink and Atuahene-Gima (2000)	The Effect of Sales Force Adoption on New Product Selling Performance	

Table 10 (continued)

Authors, Year	Title	Main results
Hyytinen et al. (2015)	Does innovativeness reduce startup survival rates?	Innovation does not always have a beneficial impact on companies because pursuing innovation sometimes leads to risky and complicated processes.
Samuelsson and Davidsson (2009)	Does venture opportunity variation matter? Investigating systematic process differences between innovative and imitative new ventures	
Scherer and Harhoff (2000)	Technology policy for a world of skew-distributed outcomes	Innovation does not always have a beneficial impact on companies because of unpredictable returns.
Brown et al. (2012)	Do financing constraints matter for R&D?	Innovative start-ups have few collateralizable assets and long and uncertain payback times; it follows that they have limited access to external credit, which determines a greater likelihood of failure.
Minetti (2011)	Informed Finance and Technological Conservatism	
Ferrucci et al. (2021)	Financial constraints and the growth and survival of innovative start-ups: An analysis of Italian firms	
Berger and Udell (2006)	A more complete conceptual framework for SME finance	
DeTienne et al. (2015)	Making sense of entrepreneurial exit strategies: A typology and test	Innovative entrepreneurs may have a particular exit strategy of innovative entrepreneurs in mind, leading to an increase of the firm's risk profile.
Branzei and Vertinsky (2006)	Strategic pathways to product innovation capabilities in SMEs	The entire innovation process requires firms to have the organizational resources and ability to reap its benefits.
Howell et al. (2005)	Champions of product innovations: defining, developing, and validating a measure of champion behaviour	
Junkunc (2007)	Managing radical innovation: The importance of specialized knowledge in the biotech revolution	
Sethi and Sethi (2009)	Can Quality-Oriented Firms Develop Innovative New Products?	
Thornhill (2006)	Knowledge, innovation and firm performance in high- and low-technology regimes	

Table 10 (continued)

Authors, Year	Title	Main results
Panel B: The importance of how innovation is measured		
Rosenbusch et al. (2011)	Is innovation always beneficial? A meta-analysis of the relationship between innovation and performance in SMEs	How innovation is measured is critical to understanding the effect on firm survival.
Dewangan and Godse (2014)	Towards a Holistic Enterprise Innovation Performance Measurement System	
Dziallas and Blind (2019)	Innovation indicators throughout the innovation process: An extensive literature analysis	
Heredia Pérez et al. (2019)	New approach to the innovation process in emerging economies: The manufacturing sector case in Chile and Peru	
Love and Roper (2015)	SME innovation, exporting and growth: A review of existing evidence	
Esteve-Pérez and Mañez-Castillejo (2008)	The Resource-Based Theory of the Firm and Firm Survival	Firms that develop firm-specific assets through advertising and making R&D enjoy better survival prospects.
Park et al. (2010)	Firm size, age, industrial networking, and growth: a case of the Korean manufacturing industry	R&D investments facilitate firm survival.
Ericson and Pakes (1995)	Markov-Perfect Industry Dynamics: A Framework for Empirical Work	The effect of R&D investment on firm survival is indeterminate, as it depends on the stochastic outcomes of the investment, the success of other firms, and the competitive pressure from outside the industry.
Coad and Guenther (2013)	Diversification patterns and survival as firms mature	Survival prospects are enhanced by innovativeness.
Koch et al. (2013)	The role of employees for post-entry firm growth	High-skilled and young workers are conducive to firms' survival.
Helmers and Rogers (2010)	Innovation and the Survival of New Firms in the UK	Owning intellectual property is positively associated with firms' survival.

Table 10 (continued)

Authors, Year	Title	Main results
Buddelmeyer et al. (2010)	Innovation and the determinants of company survival	The empirical measures of innovativeness are frequently *ex-post* indicators.
Artz et al. (2010)	A Longitudinal Study of the Impact of R&D, Patents, and Product Innovation on Firm Performance: A Longitudinal Study of the Impact of R&D, Patents, and Product Innovation	
Mairesse and Mohnen (2002)	Accounting for Innovation and Measuring Innovativeness: An Illustrative Framework and an Application	
Pandit et al. (2011)	The Effect of Research and Development (R&D) Inputs and Outputs on the Relation between the Uncertainty of Future Operating Performance and R&D Expenditures	
Santarelli and Vivarelli (2007)	Entrepreneurship and the process of firms' entry, survival and growth	
Wagner and Cockburn (2010)	Patents and the survival of Internet-related IPOs	Innovation measured by patents enhances survival prospects.
Colombelli et al. (2013)	Properties of knowledge base and firm survival: Evidence from a sample of French manufacturing firms	
Buddelmeyer et al. (2010)	Innovation and the determinants of company survival	Past success in radical innovation enhances survival prospects, and firms are more likely to fail immediately after investing in radical innovation.
Roberts (1990)	Evolving Toward Product and Market-Orientation: The Early Years of Technology-Based Firms	It is essential to refer to specific measures of "innovativeness", which can positively contribute to start-ups' survival.
Wolff (2007)	Forget R&D spending-think innovation	
Panel C: The role of innovation on Italian innovative start-ups		
Fiorentino et al. (2021)	The early growth of start-ups: innovation matters. Evidence from Italy	Differences in growth of innovative start-ups can be explained by the different levels and measures of innovativeness.

Table 10 (continued)

Authors, Year	Title	Main results
Colombelli et al. (2020)	To what extent do young innovative companies take advantage of policy support to enact innovation appropriation mechanisms?	The use of financial policy measures are associated with both formal and informal instruments, while labour policy measures are related only to formal instruments.
Audretsch et al. (2020)	Innovative start-ups and policy initiatives	Policy initiatives, managerial issues and research approaches are conceptually different, depending on the specific stage of firm development.
Calcagnini et al. (2016)	The role of universities in the location of innovative start-ups	Geographical proximity favours the transfer of knowledge and technology from universities to industries; therefore, it is a positive factor for regional economic development.
Colombelli, 2016	The impact of local knowledge bases on the creation of innovative start-ups in Italy	The features of local economic systems (e.g., size, variety and similarity of the knowledge stock) play a key role in shaping the creation of innovative start- ups.

Appendix B

As highlighted by Manjón-Antolín and Arauzo-Carod (2008), the Cox Proportional Hazards model, thanks to its simplicity and interpretability, is widely used in entrepreneurship literature for modelling firm survival.

However, to use the Cox Proportional Hazards model, the Proportionality Hazards Assumption (PHA) needs to be satisfied for estimates to be non-biased. We therefore initially estimate our model with the Cox model and then test the proportionality assumption on the basis of the Schoenfeld residuals diagnostic (Grambsch & Therneau, 1994). We perform the test both globally and for each covariate. The null hypothesis of a zero slope is equivalent to testing that the log hazard ratio is constant over time. Therefore, if we reject the null hypothesis, this indicates that our data deviate from the PHA. Table 11 shows the results of the PHA test: we obtain a global $\chi^2(25) = 77.74$ (p-value < 0.01), and must therefore reject the null hypothesis. We thus opt for the parametric Accelerated Failure Time (AFT) models.

Table 11 Proportional Hazard assumption test

Variables	rho	chi2	df	Prob > chi2
REQ1	0.10	4.53	1	0.03
REQ2	0.14	9.50	1	0.002
REQ3	0.16	15.79	1	0.0001
WOMEN	0.05	1.89	1	0.17
YOUNG	− 0.06	2.29	1	0.13
FOREIGN	0.04	1.02	1	0.31
ROA(t-1)	− 0.14	6.19	1	0.01
SIZE(t-1)	0.13	12.60	1	0.0004
LEVERAGE(t-1)	0.01	0.02	1	0.88
INCUBATOR	− 0.001	0.00	1	0.97
GLOBAL TEST		77.85	40	0.0003

Table 11 reports the test for the proportionality assumption both for individual variables and globally. Values for Year, Region and Sector FE are not significant and are, thus, omitted to ease the reading. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise

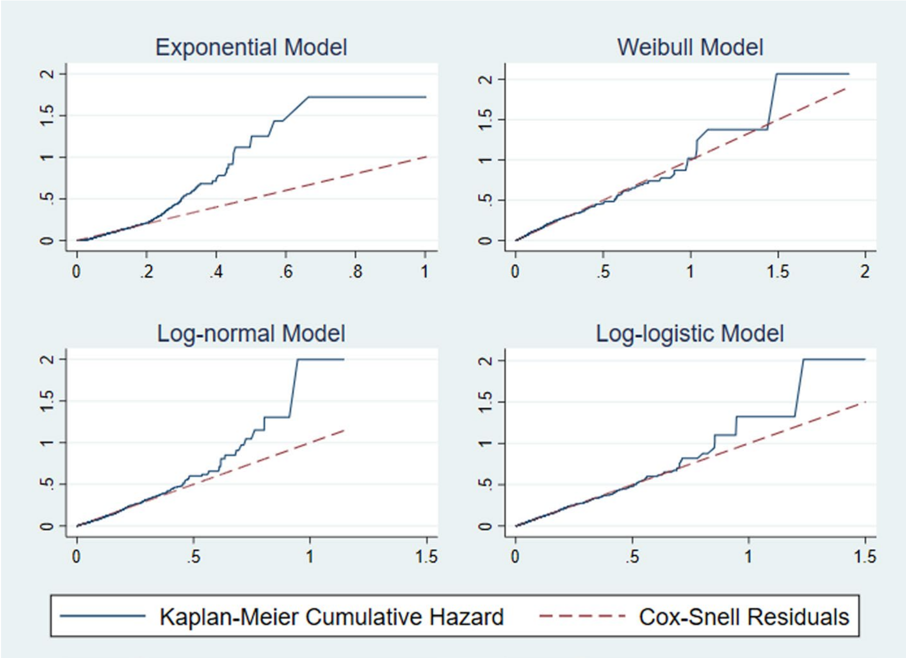

Fig. 3 Cox-Snell Residuals diagnostic plot

AFT models require a parametric form to be chosen for the error terms. However, this choice must be justified by the empirical evidence given by the data. In fact, as highlighted by George et al. (2014) the distribution is chosen by means of a graphical inspection of the Cox-Snell residuals and comparison of the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Log-likelihood (ll) values.

Figure 3 presents the plots of the Cox-Snell residuals against the Kaplan–Meier cumulative hazards curves: if the hazard function follows the 45° line, then the model fits the data well. In our case, all the models except the exponential appear to fit.

Therefore, in order to choose the best model, we also compare the AIC, BIC and Log-likelihood values: the model showing the lowest values for AIC and BIC and the highest value for Log-likelihood is preferred. From this further inspection, shown in Table 12, the Log-normal model shows the best values, and this is our main model.

We also check the presence of multicollinearity in our sample by calculating the VIF of the independent variables, which are shown in Table 13. We can observe from Table 13 that multicollinearity is not an issue in our analysis.

Table 12 Regression results for the AFT survival models with different error term distribution

	Exponential	Weibull	Log-normal	Log-logistic
REQ1	1.48***	1.09	1.09	1.10*
	(0.22)	(0.06)	(0.06)	(0.06)
REQ2	2.00***	1.23***	1.28***	1.27***
	(0.29)	(0.06)	(0.07)	(0.07)
REQ3	2.04***	1.27***	1.31***	1.31***
	(0.33)	(0.07)	(0.08)	(0.08)
WOMEN	0.80**	0.96	0.95	0.96
	(0.08)	(0.04)	(0.04)	(0.04)
YOUNG	1.10	1.01	1.01	1.00
	(0.14)	(0.05)	(0.05)	(0.05)
FOREIGN	0.54***	0.79***	0.78***	0.79***
	(0.10)	(0.06)	(0.06)	(0.06)
ROA(t-1)	1.00**	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
SIZE(t-1)	1.03	1.09***	1.10***	1.10***
	(0.03)	(0.01)	(0.01)	(0.01)
LEVERAGE(t-1)	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
INCUBATOR	1.07	1.04	1.03	1.04
	(0.12)	(0.05)	(0.05)	(0.05)
Constant	65.10***	5.45***	5.51***	4.81***
	(49.58)	(1.58)	(1.57)	(1.41)
Sector FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
chi2	44063.89***	1351.43***	1590.90***	1412.22***
ll	− 1559.83	− 1333.64	− 1313.55	− 1324.79
AIC	3207.65	2757.28	2717.10	2739.57
BIC	3561.96	3119.63	3079.46	3101.93
N	23,210	23,210	23,210	23,210

Table 12 presents the results of the AFT models estimated using Eq. (4) and a different parametric form for each estimation. We report time ratios, i.e. the exponentiated coefficients of the model. Continuous variables are lagged by 1 year. All models include region, sector and year fixed effects. Robust standard errors are clustered at firm level, in parentheses. *, **, and *** indicate significance at 10%, 5% and 1%, respectively. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise

Table 13 VIF analysis of the independent variables used in the analysis

Variable	VIF	SQRT_VIF	Tolerance
REQ1	1.81	1.35	0.55
REQ2	1.61	1.27	0.62
REQ3	1.47	1.21	0.68
WOMEN	1.02	1.01	0.98
YOUNG	1.02	1.01	0.98
FOREIGN	1.01	1.01	0.99
ROA	1.05	1.03	0.95
SIZE	1.09	1.04	0.91
LEVERAGE	1.00	1.00	1.00
INCUBATOR	1.02	1.01	0.98
GREEN	1.02	1.01	0.98

Table 13 presents the results of the VIF analysis on the main independent variables used in the analysis. The independent variables are as follows: REQ1 is represented as a dummy variable equal to 1 if the R&D expenses of a start-up are equal to or greater than 15% of the higher value of either total costs or total revenues, and 0 otherwise; REQ2 is represented as a dummy variable equal to 1 if at least 1/3 of the start-up personnel hold a Ph.D., or at least 2/3 of the personnel hold a master's degree, and 0 otherwise; REQ3 is represented as a dummy variable equal to 1 if the start-up is the owner of at least one industrial property, and 0 otherwise; WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise; GREEN is a dummy variable equal to 1 if the start-up is defined as a "high technological value company in energy related fields", and 0 otherwise

Appendix C

As noted in Sect. 5.3, our results may be biased by a treatment selection bias, since the decision to focus on a specific innovativeness dimension is dictated by choices made by the entrepreneurs themselves. This may lead to a situation in which endogeneity caused by selection bias affects the parametric survival regression results. To overcome this problem, we exploit the Heckman two-stage model (Heckman, 1979). This methodology consists of two steps: in the first step, we run a probit regression to measure the probability of focusing on a specific innovativeness dimension; in the second step, we use the results from the first step to obtain the Inverse Mills Ratio which is used as an additional covariate in the main model presented in Eq. (4). In Table 14, we present the results of the three probit regression run to calculate the probability of focusing on each innovativeness dimension. In more detail: Probit 1 indicates the model using as dependent variable a dummy equal to 1 if the start-up focuses on the R&D expenses, and 0, otherwise; Probit 2 indicates the model

Table 14 Probit regressions to define the different IMR

Dependent variable:	Probit 1 REQ1	Probit 2 REQ2	Probit 3 REQ3
WOMEN	– 0.05*	0.08***	– 0.02
	(0.02)	(0.03)	(0.03)
YOUNG	0.17***	– 0.14***	– 0.11***
	(0.03)	(0.03)	(0.03)
FOREIGN	0.15***	– 0.30***	0.00
	(0.05)	(0.05)	(0.05)
ROA(t-1)	– 0.00***	0.00***	– 0.00***
	(0.00)	(0.00)	(0.00)
ROA^2(t-1)	– 0.00**	0.00***	– 0.00
	(0.00)	(0.00)	(0.00)
SIZE(t-1)	0.10***	– 0.09***	– 0.05**
	(0.02)	(0.02)	(0.02)
SIZE^2(t-1)	– 0.01***	0.00	0.01***
	(0.00)	(0.00)	(0.00)
LEVERAGE(t-1)	– 0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
LEVERAGE^2(t-1)	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
INCUBATOR	0.03	0.08***	– 0.09***
	(0.02)	(0.02)	(0.02)
GREEN	– 0.09***	0.08***	0.16***
	(0.03)	(0.03)	(0.03)
Constant	0.04	– 0.63	– 1.13***
	(0.58)	(0.64)	(0.14)
Sector FE	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	23,210	23,210	23,205
Pseudo R^2	0.03	0.04	0.06

Table 14 presents the results of the probit regressions estimated using Eq. (5). Continuous variables are lagged by 1 year. All models include region, sector and year fixed effects. *, **, and *** indicate significance at 10%, 5% and 1%, respectively. The independent variables are as follows: WOMEN is a dummy variable equal to 1 if there is a prevalence of women in the governance of the start-up, and 0 otherwise; YOUNG is a dummy variable equal to 1 if there is a prevalence of youngsters in the governance of the start-up, and 0 otherwise; FOREIGN is a dummy variable equal to 1 if there is a prevalence of foreigners in the governance of the start-up, and 0 otherwise; ROA is the return on assets, which is a measure of firm profitability; SIZE is the natural logarithm of total assets; LEVERAGE, a measure of the level of indebtedness, is the ratio between the firm's total debt and equity; INCUBATOR is a dummy variable equal to 1 if a start-up is located in the same province of an incubator/science park, and 0 otherwise; GREEN is a dummy variable equal to 1 if the start-up is defined as a "high technological value company in energy related fields", and 0 otherwise using as dependent variable a dummy equal to 1 if the start-up focuses on a highly skilled workforce, and 0, otherwise; and Probit 3 indicates the model using as dependent variable a dummy equal to 1 if the start-up focuses on the innovative output, and 0, otherwise.

As highlighted in the literature (e.g., Certo et al., 2016; Wolfolds & Siegel, 2019) the first stage probit must contain at least one variable which is not contained in the main regression: this is called the exclusion restriction. In our case, the exclusion restriction is represented by the variable GREEN, which indicates whether the start-up is identified as a "high technological value company in energy related fields" under Italian regulations (Serio et al., 2020).

Appendix D

In this Appendix we show the cross-tabulations of the differences between the innovative start-ups created until and after 2020, based on the observables present only in the special section of the Italian Company Register dedicated to Italian innovative start-ups.

See Tables 15, 16, 17, 18, 19, 20, 21, 22, 23.

Table 15 Cross-Tabulation for the REQ1

REQ1/set up after 2020	No	Yes	Total
No	3849	1102	4951
Yes	6111	3422	9533
Total	9960	4524	14,484

Table 15 presents the cross-tabulation for REQ1 and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 282.19, p-value = 0.00

Table 16 Cross-Tabulation for REQ2

REQ2/set up after 2020	No	Yes	Total
No	7437	3589	11,026
Yes	2523	935	3458
Total	9960	4524	14,484

Table 16 presents the cross-tabulation for REQ2 and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 37.23, p-value = 0.00

Table 17 Cross-Tabulation for REQ3

REQ3/set up after 2020	No	Yes	Total
No	7929	4178	12,107
Yes	2031	346	2377
Total	9960	4524	14,484

Table 17 presents the cross-tabulation for REQ3 and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 368.28, p-value = 0.00

Table 18 Cross-Tabulation for WOMEN

WOMEN/set up after 2020	No	Yes	Total
No	8694	3928	12,622
Yes	1266	596	1862
Total	9960	4524	14,484

Table 18 presents the cross-tabulation for WOMEN and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 0.60, p-value = 0.44

Table 19 Cross-Tabulation for YOUNG

YOUNG/set up after 2020	No	Yes	Total
No	8519	3544	12,063
Yes	1441	980	2421
Total	9960	4524	14,484

Table 19 presents the cross-tabulation for YOUNG and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 115.67, p-value = 0.00

Table 20 Cross-Tabulation for FOREIGN

FOREIGN/set up after 2020	No	Yes	Total
No	9637	4337	13,974
Yes	323	187	510
Total	9960	4524	14,484

Table 20 presents the cross-tabulation for FOREIGN and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 7.26, p-value = 0.00

Table 21 Cross-Tabulation for GREEN

GREEN/set up after 2020	No	Yes	Total
No	8500	3857	12,357
Yes	1460	667	2127
Total	9960	4524	14,484

Table 21 presents the cross-tabulation for GREEN and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 0.02, *p*-value = 0.89

Table 22 Cross-Tabulation for sectoral distribution

Sector/set up after 2020	No	Yes	Total
A	73	35	108
C	1586	556	2142
D	101	12	113
E	26	5	31
F	102	40	142
G	298	138	436
H	18	12	30
I	49	13	62
J	4804	2454	7258
K	26	11	37
L	18	8	26
M	2345	1008	3353
N	282	142	424
P	102	47	149
Q	61	13	74
R	40	14	54
S	29	16	45
Total	9960	4524	14,484

Table 22 presents the cross-tabulation for the sectoral distribution and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 91.43, *p*-value = 0.00

Table 23 Cross-Tabulation for geographical distribution

Province/set up after 2020	No	Yes	Total
AG	8	5	13
AL	23	22	45
AN	79	38	117
AO	14	8	22
AP	64	27	91
AQ	61	23	84
AR	29	15	44
AT	7	8	15
AV	75	29	104
BA	218	135	353
BG	223	71	294
BI	18	10	28
BL	12	7	19
BN	41	23	64
BO	231	120	351
BR	24	19	43
BS	200	93	293
BZ	89	39	128
CA	79	43	122
CB	49	7	56
CE	149	48	197
CH	30	17	47
CL	40	8	48
CN	74	32	106
CO	54	45	99
CR	26	12	38
CS	77	19	96
CT	162	49	211
CZ	60	21	81
EN	12	4	16
FE	37	16	53
FG	39	15	54
FI	138	102	240
FM	25	14	39
FO	40	29	69
FR	35	22	57
GE	116	82	198
GO	13	6	19
GR	6	4	10
IM	11	4	15
IS	22	4	26
KR	14	4	18
LC	27	13	40
LE	125	37	162
LI	24	16	40

Table 23 (continued)

Province/set up after 2020	No	Yes	Total
LO	20	5	25
LT	45	18	63
LU	46	31	77
MB	98	58	156
MC	51	36	87
ME	78	16	94
MI	1827	939	2766
MN	29	13	42
MO	120	43	163
MS	15	8	23
MT	28	7	35
NA	478	183	661
NO	36	19	55
NU	14	6	20
OR	14	3	17
PA	168	36	204
PC	33	24	57
PD	236	98	334
PE	52	24	76
PG	123	41	164
PI	111	35	146
PN	52	12	64
PO	15	19	34
PR	81	31	112
PS	49	17	66
PT	22	8	30
PV	55	15	70
PZ	79	32	111
RA	53	20	73
RC	66	5	71
RE	79	28	107
RG	25	10	35
RI	14	3	17
RM	1065	506	1571
RN	62	40	102
RO	29	13	42
SA	217	78	295
SI	26	10	36
SO	7	4	11
SP	13	8	21
SR	30	7	37
SS	39	23	62
SV	8	6	14
TA	34	24	58
TE	62	20	82

Table 23 (continued)

Province/set up after 2020	No	Yes	Total
TN	140	55	195
TO	334	178	512
TP	21	5	26
TR	37	33	70
TS	37	24	61
TV	111	43	154
UD	92	31	123
VA	74	33	107
VB	5	1	6
VC	4	0	4
VE	108	40	148
VI	116	52	168
VR	153	65	218
VT	21	15	36
VV	3	2	5
Total	9960	4524	14,484

Table 23 presents the cross-tabulation for the geographical distribution and the Chi-square test to test whether the differences observed between firms set up until and after 2020 are statistically significant

Pearson Chi2 = 266.43, p-value = 0.00

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