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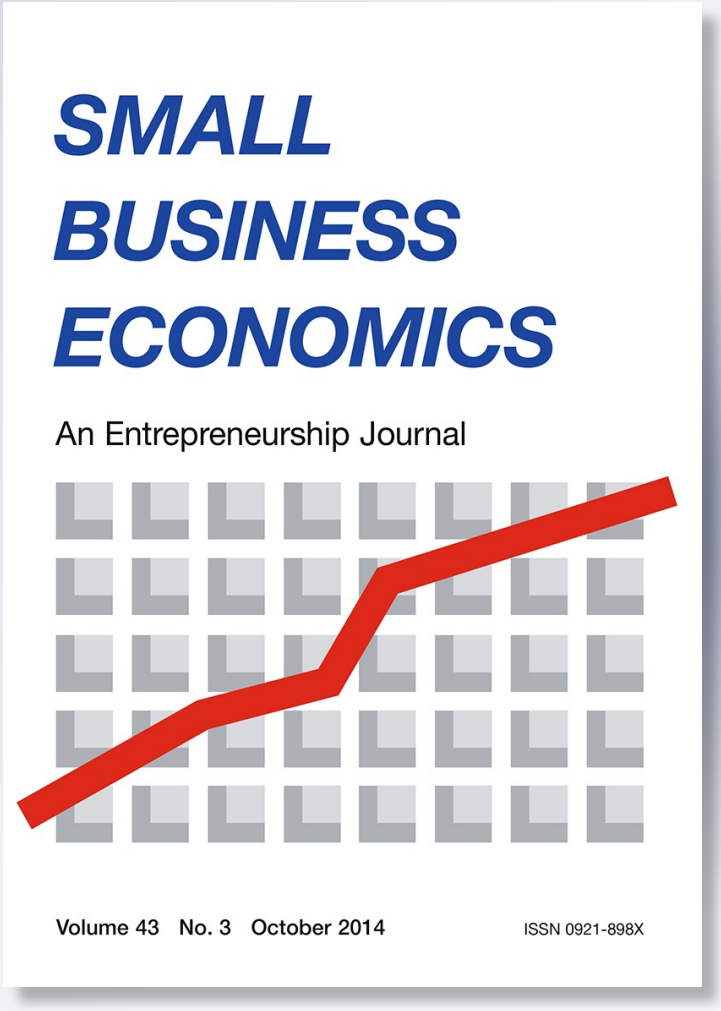

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Metropolitan innovation, firm size, and business survival in a high-tech industry

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Abstract This paper contributes to the growing body of business survival literature that focuses on regional determinants of the hazard faced by firms. Using parametric survival analysis, we test the effects of regional innovation on exit likelihood in the US computer and electronic product manufacturing during the 1992–2008 period. The novelty of our approach is in conditioning the effects of metropolitan innovation on firm size. Estimation results suggest a negative relationship between metropolitan patenting activity and survival of firms that started with 1–3 employees. This effect decreases if companies grow. Establishments with more than 4 employees at start-up are insensitive to metropolitan innovation, although size of firms that started with 4–9 employees improves their survival chances. These findings indicate that local knowledge spillovers do not translate into lower hazard. The negative relationship indicates either a creative destruction regime or decisions of entrepreneurs to shut down existing ventures in order to pursue other opportunities.

Keywords Business survival · Metropolitan innovation · Survival analysis · Computer and electronic product manufacturing

JEL Classifications C41 · L26 · L63 · R1

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1 Introduction

Empirical research shows that start-ups contribute more than incumbent firms to job creation (Acs and Armington 2004). Also, their role in technological evolution is crucial in the long run (Fritsch and Mueller 2004). Many firms, however, exit soon after entry, as only about half of them survive beyond 5 years (Audretsch and Mahmood 1995; Dunne et al. 1989; Johnson 2005; Mata et al. 1995). Exit of a firm does not necessarily imply a failure (Bates 2005; Esteve-Perez et al. 2010). Mergers and acquisitions (M&A) are often regarded as a successful exit. Likewise, a company may decide to exit in order to pursue other business opportunities. Regardless of the business success an exit might indicate, spending public dollars to facilitate the establishment of short-lived companies is likely to be tantamount to an inefficient use of resources. For this reason, knowledge of factors contributing to firm survival is of practical importance for policy-makers as

they strive to implement programs designed to stimulate economic activity (Renski 2011). The desired outcomes of such policies are often couched in terms of increased firm formation and, most importantly, successful performance of start-ups.

Perhaps for this reason, firm survival has become a popular topic of research in the last decades. The extant business survival literature presents adequate explanation of how a company's internal characteristics and activities, and the nature of the industry and relevant markets, affect its survival chances. In stark contrast, our knowledge of the regional determinants of firm exits remains rather limited (Brixy and Grotz 2007; Manjon-Antolın and Arauzo-Carod 2008). Although increasing attention has recently been paid to geographical factors (Buehler et al. 2012; Renski 2011; Tsvetkova et al. 2014), a pronounced gap in understanding the relationship between a regional milieu and business survival remains. As most policies are regional in nature, knowledge of the degree of leverage that policy-makers may have on issues of firm survival is essential for educated policy design. If regional attributes are confirmed to systemically influence firm survival, regional development policies can be crafted to selectively stimulate the flourishing of attributes favorable to survival, or alternatively to encourage start-ups to locate in regions where auspicious conditions prevail. This paper contributes to the business literature and policy discourse by investigating the effects of one regional characteristic, namely metropolitan innovation, on survival of high-technology firms that did not experience M&A.

We study computer and electronic product manufacturing (NAICS334), as this industry critically depends on innovations and should be particularly perceptive to innovative environment. This industry employs a disproportional number of researchers and engineers whose goal is to develop new products and to improve existing ones (BLS 2009). At the same time, understanding business survival dynamics in NAICS334 is important due to the industry's special role in the US economy. The computer and electronic product manufacturing industry promotes innovation, provides high-wage employment that has remarkable multiplier effects, and accounts for more than 10 % of value added in manufacturing.

In the most complete account of the relationship between regional external economies and business survival to date, Renski (2011) carefully examines the impacts of localization, urbanization, and diversity on survival likelihood in selected US industries as proposed by agglomeration theory. He explains the positive relationship between these three determinants and the hazard faced by firms in several industries by knowledge spillovers, among other factors.

To continue on the importance of knowledge, recent growth theories postulate that innovation and associated knowledge and technological spillovers determine economic growth in general, and firm performance in particular. Knowledge is the main strategic resource that a firm has at its disposal in the modern economy (Spender 1996). A business can either generate innovative knowledge via R&D and other practices, or learn from other firms, or both. Learning from others is a form of knowledge spillovers, which increase productivity, may lead to increasing returns to scale (Griliches 1992; López-Bazo et al. 2004), and therefore enhance the chances of survival. The empirical literature suggests that small firms are more likely to rely on knowledge spillovers, because their own ability to invest resources in knowledge production is usually limited (Audretsch and Vivarelli 1996). This observation implies that one should expect a positive effect of regional innovative environment on business survival as knowledge is more easily acquired from nearby innovators.

Conversely, a regional innovative environment is intrinsically related to the so-called 'creative destruction' regime.[1] Firms are usually innovative during the initial stages of their development, when they try to find their niche in the market. Novelty helps new firms succeed in competing against incumbents. By driving incumbents to reinvent themselves or to go out of business, entrepreneurial companies achieve some market power, which does not stimulate innovation. After a firm stops creating new combinations and settles into running its business just like others, it loses entrepreneurial character and is likely to end up exiting, while new innovative firms keep introducing new combinations to the economy (Schumpeter 1942). The process by which less entrepreneurial firms are driven out of business by more entrepreneurial ones is the nature of 'creative destruction'. It is our contention in this paper that, along this line

[1] Marx and Engels coined the term 'creative destruction' in *The Communist Manifesto* first published in 1848. Here, we use the Schumpeterian perspective on creative destruction (Schumpeter derived his notion of 'creative destruction' from the Marxist definition), which has a different meaning from the one originally proposed.

of reasoning, more innovative regions should experience greater 'creative destruction', i.e. more firms entering and exiting the market, which in turn diminishes the likelihood of survival.

Lastly, research-intensive regions may offer plentiful business opportunities lacking in less innovative metropolitan areas. If business owners believe that shutting down existing businesses in order to re-channel the resources to start a new venture would give a greater return, one should expect a positive relationship between regional innovation and exit likelihood.

In this paper, we empirically test these two contrasting perspectives on the possible effects of regional innovation on business survival using data for the US computer and electronic product manufacturing industry during the 1992–2008 period. We use parametric survival analysis to conduct this study. The novelty of our approach is in conditioning the effects of regional characteristics (metropolitan innovation) on firm attributes (start-up and current size). The empirical literature shows that the effects of firm size may depend on the product and industry life cycle (Agarwal 1997; Agarwal and Audretsch 2001; Agarwal and Gort 2002; Agarwal et al. 2002), while the interaction of firm size with regional factors has not yet been studied.

The rest of this paper is organized as follows. The next section briefly reviews the literature on business survival, agglomerated economies and knowledge spillovers, as well as other relevant perspectives. Section 3 presents the computer and electronic product manufacturing industry as an industry in which either of the two main perspectives on business longevity[2] may hold. Section 4 presents data sources and the sample used in this study. The estimation approach and variables are described in Sects. 5 and 6, followed by estimation results in Sect. 7. The last section contains concluding remarks and proposes avenues for further research.

2 Literature review

Traditionally, the empirical literature on business survival has focused on firm- and industry-specific characteristics. In recent years, however, researchers have started to pay increasing attention to the geographic determinants of firm longevity (Brixy and Grotz 2007; Buehler et al. 2012). The justification for linking regional characteristics to economic outcomes in general, and firm performance in particular, may come from at least four theoretical frameworks, namely the new economic geography (Fujita and Krugman 2004; Fujita et al. 1999; Fujita and Thisse 2009), agglomeration theory that suggests local knowledge spillovers (Jaffe and Trajtenberg 1996; Jaffe et al. 1993; Marshall 1920 [1890]), cluster theory (Porter 1990, 1998a, b), and the regional innovative systems perspective (Rodriguez-Pose and Crescenzi 2008; Uyarra 2010). In most general terms, the relationship between regional characteristics and economic performance postulated by these frameworks relies on two types of factors: those related to the environment for doing business, such as specialized suppliers and appropriate labor pool, and knowledge-related factors. The latter group appears to be more prominent in the discussion of regional effects. This is hardly surprising given that knowledge is nowadays the main strategic business resource (Spender 1996), which is only partially excludable (Romer 1990) and tends to spill over on businesses within some geographic boundaries (Adams and Jaffe 1996; Bottazzi and Peri 2003; Rodriguez-Pose and Crescenzi 2008; Wang et al. 2004).

Agglomeration theory to a varying degree incorporates elements from the other three frameworks and is the most relevant for our research. One may expect companies to face a lesser hazard in geographic areas with greater accumulated stock of economically useful knowledge (Acs and Plummer 2005) and close spatial proximity because local knowledge spillovers (LKS) should increase productivity as a result of increased innovation and adoption of new technologies (Feldman and Audretsch 1999; Jaffe et al. 1993; Koo 2005a). Besides, knowledge spillovers provide information about business opportunities in a region (Porter 1998b), thus reducing the likelihood of an entry mistake, a possible reason for exit (Jovanovic 1982). If learning and knowledge spillovers occur, firms located in the areas with intensive innovative activities, and formally not engaged in R&D, should become more efficient and innovative, face less uncertainty, and enjoy higher likelihood of survival.

A drastically different perspective suggests a negative relationship between innovation in a region and

[2] We use the terms "business longevity" and "business survival" interchangeably throughout the paper.

Table 1 Summary of research on the effects of firm- and industry-level characteristics on business survival

Characteristic	Relationship to firm survival	References
Characteristics of business owner or managerial team/key employees		
Age	Positive	Headd (2003), Nafziger and Terrell (1996), Persson (2004)
	Insignificant	Saridakis et al. (2008)
Relevant experience	Positive	Arribas and Vila (2007), Headd (2003), Wilbon (2002)
Education	Positive	Colombo and Grilli (2007), Headd (2003), Santarelli and Vivarelli (2007), Saridakis et al. (2008)
	Negative	Nafziger and Terrell (1996), Persson (2004)
	Insignificant	Arribas and Vila (2007)
Diverse background	Positive	Aspelund et al. (2005), Headd (2003), Littunen (2000)
Firm characteristics		
Age	Positive (liability of newness)	Fontana and Nesta (2010), Lin and Huang (2008)
	Positive, then negative (liability of adolescence)	Agarwal and Gort (2002), Esteve-Pérez and Mañez-Castillejo (2008), Esteve-Perez et al. (2004), Kaniovski and Peneder (2008), Nikolaeva (2007), Fackler et al. (2013)
	Insignificant	Agarwal et al. (2002), Buddelmeyer et al. (2010), Levitas et al. (2006)
Size	Positive (liability of smallness)	Audretsch et al. (2000), Fackler et al. (2013), Fotopoulos and Louri (2000), Kaniovski and Peneder (2008), Levitas et al. (2006), Mata et al. (1995), Persson (2004), Segarra and Callejón (2002), Strotmann (2007)
Innovation	Positive	Audretsch (1991), Esteve-Pérez and Mañez-Castillejo (2008), Esteve-Perez et al. (2004), Fontana and Nesta (2010), Huergo and Jaumandreu (2004)
	Negative	Boyer and Blazy (2013), Buddelmeyer et al. (2010), Reid and Smith (2000)
Capital intensity	Positive	Audretsch et al. (2000), Fotopoulos and Louri (2000)
Productivity and profitability	Positive	Bellone et al. (2008), Esteve-Pérez and Mañez-Castillejo (2008), Esteve-Perez et al. (2010), Fotopoulos and Louri (2000), Segarra and Callejón (2002)
Exporting	Positive	Esteve-Pérez and Mañez-Castillejo (2008), Esteve-Perez et al. (2004, 2010)
Being a subsidiary/branch	Positive	Bayus and Agarwal (2007), Buenstorf (2007), Fontana and Nesta (2010), Persson (2004)
Venture capital backing	Positive	Jain and Kini (2000)
Financial constraints	Negative	Bridges and Guariglia (2008), Fotopoulos and Louri (2000), Headd (2003), Musso and Schiavo (2008), Saridakis et al. (2008)
Industry characteristics		
Capital intensity	Negative	Audretsch and Mahmood (1995), Lin and Huang (2008)
Market power	Positive	Lin and Huang (2008), Segarra and Callejón (2002)
	Negative	Bellone et al. (2008), Strotmann (2005)
Expanding industries	Positive	Bellone et al. (2008), Kaniovski and Peneder (2008), Mata et al. (1995), Segarra and Callejón (2002)
Mature industries	Negative for young firms	Agarwal and Gort (2002), Manjon-Antolın and Arauzo-Carod (2008)

business survival. This relationship may be determined by factors that are external or internal to a firm. Competitive pressure is an external factor, while decision of a business owner to discontinue operation for various reasons is an internal one.

As argued by Schumpeter (1942), industries with active entry are more innovative (entrepreneurial in his parlance). They should exert greater competitive pressure forcing incumbents, who are less likely to innovate, out of business. Indeed, empirical studies show that active industry entry decreases the average business life expectancy (Kaniovski and Peneder 2008), while competition is more intense in highly technological and innovative sectors (Agarwal and Gort 2002; Audretsch 1995; Segarra and Callejón 2002). This argument can be readily extended to regions in the case of industries that are dependent predominantly on local markets either in component acquisition, or when selling the final product. In such instances one may speak of regions that differ in the intensity of 'creative destruction'. Firms in more innovative regions, particularly those not engaged in research and development, are likely to be disadvantaged and face a higher hazard due to increased competitive pressure.

Vibrant regions characterized by intensive innovation may offer greater business opportunities. In this case, shutting down a company to pursue a more promising venture may be the optimal strategy for an entrepreneur. For example, Bates (2005) finds that alternative business opportunities are a key reason for business closure among small young companies in the US

In addition to research efforts devoted to the study of geographical determinants of business survival, extensive literature investigates firm- and industry-level factors that affect firm longevity. Table 1 succinctly presents current knowledge in this area followed by a brief discussion.

Human capital available to a firm is perhaps the most decisive performance factor among individual characteristics. Relevant experience of an owner or a manager consistently decreases hazard faced by a firm (Arribas and Vila 2007; Headd 2003; Wilbon 2002). The size and diverse backgrounds of the co-founders or a management teams usually translate into increased probability to stay in business (Aspelund et al. 2005; Headd 2003; Littunen 2000). The evidence on the effects of education is controversial. In the US, and in knowledge intensive industries in Europe, the education level of manager(s) or owner(s) is found to decrease hazard rates (Colombo and Grilli 2007; Headd 2003; Santarelli and Vivarelli 2007; Saridakis et al. 2008). On the other extreme, several studies report negative or insignificant relationship between educational attainment and survival prospects (Arribas and Vila 2007; Nafziger and Terrell 1996; Persson 2004). In fact, entrepreneurs with an education level below average establish a substantial share of firms (Christensen 1997; Dahl and Reichstein 2005).

Firm characteristics that affect business survival are inherently related to resource access. Predictably, greater resourcefulness of a company enhances its survival chances. The empirical literature shows that size (Audretsch et al. 2000; Fackler et al. 2013; Fotopoulos and Louri 2000; Kaniovski and Peneder 2008) and age, at least to a certain point (Agarwal and Gort 2002; Fackler et al. 2013; Fontana and Nesta 2010), reduce hazard. Other factors related to lower hazard are the firm status of an exporter, a subsidiary, or a branch, and access to venture capital financing (Bayus and Agarwal 2007; Esteve-Pérez and Mañez-Castillejo 2008; Esteve-Perez et al. 2010; Jain and Kini 2000). Successful innovation, capital intensity, profitability, and productivity usually lead to a longer lifespan for a firm (Audretsch 1991; Bellone et al. 2008; Fotopoulos and Louri 2000). In contrast, financial constraints (Bridges and Guariglia 2008; Headd 2003; Musso and Schiavo 2008), as well as costs of innovation that are beyond a company's means (Boyer and Blazy 2013), increase the likelihood of exit.

Industrial characteristics shown to influence business survival include capital intensity, market power, and the stage of industrial life cycle. A positive relationship between capital intensity and firm longevity reported by several studies (Audretsch and Mahmood 1995; Lin and Huang 2008) may be the result of self-selection when more resourceful firms enter capital-intensive industries in a hope of less competition (Doms et al. 1995). Lower competition promotes (Lin and Huang 2008; Segarra and Callejón 2002) or hampers (Bellone et al. 2008; Strotmann 2005) business survival, depending on specific circumstances. Expanding industries usually provide favorable conditions for both incumbents and new entrants, which tend to stay in business longer compared to the companies in stable or contracting

sectors (Bellone et al. 2008; Kaniovski and Peneder 2008; Mata et al. 1995; Segarra and Callejón 2002).

3 Computer and electronic product manufacturing industry

Industries differ substantially in terms of propensity to exit (Dunne et al. 1989), possibly due to the differences in local knowledge spillovers intensity (Glaeser et al. 1992), competition regime (Fritsch et al. 2006; Segarra and Callejón 2002), minimum efficient scale (Fritsch et al. 2006), firms' absorptive capacity (Fabrizio 2009), and other characteristics. In this paper, we focus our analysis on computer and electronic product manufacturing.[3] Although the results of this research may not be readily generalizable to other manufacturing industries because of such restriction, understanding business survival determinants within the NAICS334 industry is important due to the significance of computer and electronics manufacturing for the US economy. Recent research shows that this industry provides high-wage employment and plays an important role in industrial innovation, trade deficit reduction, environmental sustainability (Helper et al. 2012), and growth (Koo 2005b). On average, NAICS334 accounts for about 11 % of all the value added by the US manufacturing (approximately 1.7 % of GDP)[4], and its multiplier effect across the economy is substantial.[5]

Computer and electronic product manufacturing is well suited for the study of external effects of innovation on business survival for several reasons. First, it is an industry that consistently ranks as one of the most innovative. Its success is largely based on the development and introduction of new products, technologies, and software. There is a high pressure on NAICS334 companies to innovate, thus explicit emphasis on R&D in their day-to-day operations (BLS 2011).

In addition, despite the fact that the computer and electronic product manufacturing industry is global when it comes to selling finished products, the intermediate production stages tend to be local. Computers and electronics contain multiple components, produced by different companies. According to the Bureau of Labor Statistics, NAICS334 firms that produce intermediate components and finished products prefer to locate in close proximity in order to enjoy immediate access to innovations (BLS 2009). The local dimension of the industry makes both the knowledge spillovers argument and the 'creative destruction' hypothesis pertinent as two possible explanations for the relationship between metropolitan innovative environment and firm survival.

4 Data and sample

The National Establishment Time Series (NETS) Database for years 1991–2008 is the main data source used for this analysis. The NETS Database is created by Walls and Associates from the Dun and Bradstreet's (D&B) DUNS Marketing Information archive. The database consists of yearly snapshots of the US economy (all firms recoded by D&B to be active) performed every January since 1990. The database is updated every summer. If an establishment goes out of business, its last year of operation is indicated but the record is not removed. This allows for the study of active companies and establishments that have exited. The NETS file available for this research is a subset of the original database. The file contains longitudinal information about each establishment started in 1991, including company name, county FIPS code, years of operation (first and last years in the dataset, year the business started), industry classification (6-digit NAICS code), type of establishment (standalone, branch, headquarter), and the number of employees. We supplement the NETS Database with data available from the US Patent and Trademark Office (PTO), the Census Bureau, the Bureau of Labor Statistics, and the Integrated Postsecondary Education Data System.

For our sample, we identify all establishments that were started in year 1991 and track them till 2008, the last year of data availability. To mitigate a potential risk of aggregation bias we use only stand-alone

[3] The industry consists of NAICS 3341 (computer and peripheral equipment manufacturing), NAICS 3342 (communications equipment manufacturing), NAICS 3343 (audio and video equipment manufacturing), NAICS 3344 (semiconductor and other electronic component manufacturing), NAICS 3345 (navigational, measuring, electromedical, and control instruments manufacturing), and NAICS 3346 (manufacturing and reproducing magnetic and optical media).

[4] http://www.bea.gov/industry/gdpbyind_data.htm.

[5] For instance, the multiplier effect of computer manufacturing is estimated to be 16 in California (DeVol et al. 2009).

Table 2 Total number of NAICS334 start-ups in 1991, and establishments in the estimation file

Description[a]	Number of firms
Total number of start-ups in 1991	2,658
Outside of continental USA	11
Outside MSAs	229
Not independent	261
Experienced M&A	12
Have more than 100 employees in 1992	6
Outliers	1
Missing/erroneous data in NETS	385
Total establishments in the sample	1,803

Source NETS Database, US PTO, The Deal Pipeline, WRDS, Alacra Store

[a] These categories are not exclusive

establishments in US MSAs in our analysis; retained establishments also had less than 100 employees in 1992, and did not experience merger or acquisition. Table 2 presents all categories of firms that were removed from the estimation file and firm count by category. The final sample consists of 1,803 establishments, 1,122 of which exited over the observation period as shown in Fig. 1.

5 Econometric analysis

We use parametric survival analysis to estimate the effects of metropolitan innovation and firm size on business survival in the US computer and electronic product manufacturing industry. The validity of parametric estimation results critically depends on the appropriate exit distribution that is hypothesized. The literature suggests a high likelihood of firm exit during the first years in business, which decreases over time (Fackler et al. 2013). The smoothed hazard estimates (Fig. 2) and the dynamics of exits in our sample (Fig. 1) exhibit the same pattern. For this reason, we use the log-logistic distribution, which allows for initially increasing and subsequently decreasing hazard.

Business survival is a function of multiple factors at various levels. Individual company characteristics are likely to play a central role in the ability of a firm to live longer. Often such characteristics are not observable to a researcher. To account for unobserved heterogeneity at the establishment level, we fit a shared frailty model. Under this specification, hazard faced by a company over years is not independent; all observations for the same firm share frailty, which is assumed to follow a gamma distribution.[6]

We first perform the analysis using all establishments in our sample to depict the overall pattern of effects on business survival. In the next step, we estimate the same model separately on three subsamples of firms determined by the number of employees at start-up. The additional analyses provide a deeper understanding of the conditioning role played by firm size on the relationship between metropolitan innovation and longevity.

The empirical literature often distinguishes companies with one to three employees (Fackler et al. 2013), one to nine employees (Arvanitis and Stucki 2013; Uhlaner et al. 2013), or up to 25 employees (Rosenthal and Strange 2003) as separate groups. We divide our sample into three groups. The first group contains businesses that had one to three employees in 1992 (798 firms); the second group includes companies with four to nine employees in 1992 (630 firms), and all other firms constitute the third group (375 firms). For the purposes of this analysis, we refer to these groups as small firms, medium firms, and large firms, respectively.

6 Explanatory and control variables

For survival analysis, only independent variables need to be specified, as the dependent one, the hazard rate, is estimated implicitly. The main explanatory variables in this study are the level of metropolitan innovation (*Innovation*), firm size (*Size*), and an interaction term between *Innovation* and *Size* (*InnovSize*). Innovation in a region may be measured in a number of ways. Patenting intensity, R&D expenditures, or share of R&D employees are commonly used in the literature. Yet, it is not the patents, or R&D expenditures, or share of R&D employees in the economy that directly increase productivity and make regional economies more innovative and prosperous. The main driver of economic success demonstrated by companies and regional economies is the fruitful application of new ideas in the market. However, new ideas cannot be measured as they do not leave a paper trail, to repeat

[6] Modeling frailty as gamma distributed is standard practice (Hougaard 1995).

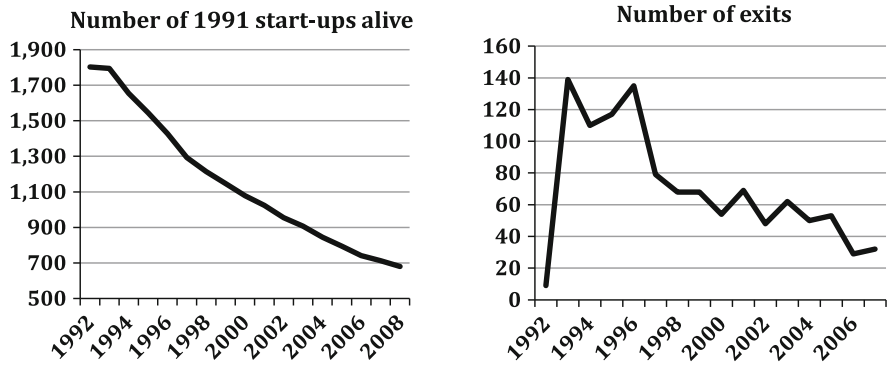

Fig. 1 Number of surviving establishments in the sample over years and exit dynamics

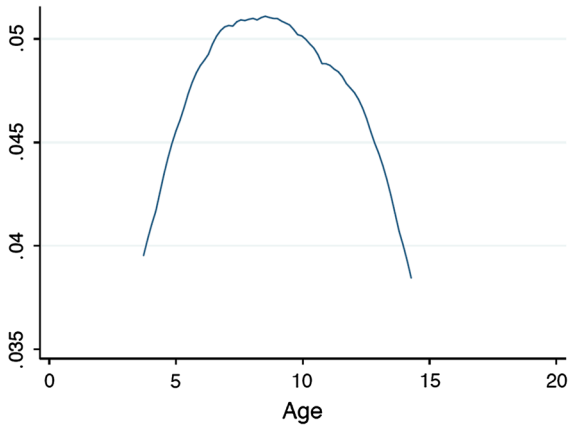

Fig. 2 Smoothed hazard estimates for the US computer and electronic product manufacturing, 1992–2008

Krugman's (1991) famous saying. Thus, researchers have to use approximations for the stock of knowledge generated in a region.

We use the natural logarithm of the population-adjusted total number of successful patent applications in a given year in a given MSA as a measure of innovation.[7] The US PTO is the data source. As a proxy for the stock of new profitable ideas, patent count has its weaknesses, as well as limitations. Patents do not cover all new ideas created in the economy; possibly the majority of them actually go unpatented. On the other hand, not every patent is utilized in the market promoting productivity and innovation. Furthermore, the number of patents as a measure of innovation is unable to reflect market value of each patent, which are likely to differ greatly (Levitas et al. 2006). Despite all these concerns, researchers have argued that patent count is perhaps the best measure of innovation (Griliches 1990), because it is superior to other available measures (Feser 2002) and is an appropriate approximation for the stock of knowledge generated in an urban region (Acs et al. 2002).

Firm size is arguably the most studied determinant of business survival. Numerous studies report the so-called "liability of smallness", a consistent positive relationship between the size of a company and its longevity (Audretsch et al. 2000; Fackler et al. 2013; Fotopoulos and Louri 2000; Kaniovski and Peneder 2008; Levitas et al. 2006; Mata et al. 1995; Persson 2004; Segarra and Callejón 2002; Strotmann 2007).[8] Researchers use various metrics to approximate the size of a business, such as the number of employees (current or at start-up), assets, or sales volume. There is some evidence that the results are in general not sensitive to the approximation chosen (Agarwal et al. 2002), although the current number of employees is preferred as a measure of firm size in the business survival literature (Mata et al. 1995). In this study, *Size* is the natural logarithm of the current number of employees as reported in the NETS Database. Variable *InnovSize* is calculated by multiplying *Innovation* by *Size*.

[7] Evaluation of a patent application is a lengthy process; in addition, there may be a delay in the US PTO system reporting of the number of patents granted. Arguably for these reasons, patent counts reported by the US PTO at the time the data were retrieved for this study decrease sharply for the last 3 years covered by the analysis. To mitigate a potential bias in estimation due to the measurement error we inflate patent counts in the years 2006, 2007, and 2008 by 5, 10, and 15 %, respectively.

[8] Several studies, however, report statistically insignificant effect of size on the probability of exit (Audretsch et al. 2000; Saridakis et al. 2008).

To factor out the effects of other possible survival determinants that are neither related to metropolitan innovation, nor to firm size, we control for a number of characteristics, including age of a firm (*Age*), its innovative activity (*Patents*), metropolitan educational attainment (*Graduates*), population density (*PopDensity*), current level of unemployment (*Unemployment*), and industry dummies at 4-digit NAICS level.[9] A number of independent variables at firm, industry, and regional levels used in the preliminary model specifications were excluded from the final analysis due to insignificance. These controls are venture capital financing of a company, change in employment from the previous year, concentration of the industry a company belongs to, population-adjusted number of new entrants in computer and electronic product manufacturing, metropolitan industrial diversity, average income in a MSA, total metropolitan population, and entrepreneurship level.

Age of a company, together with its size, is the most important factor for business survival commonly considered by empirical studies. Many of them report 'liability of newness', a decrease in hazard faced by a firm as time passes (Box 2008; Esteve-Perez et al. 2010; Jensen et al. 2008; Persson 2004). Variable *Age* is the number of years a company has been in operation. It is calculated by subtracting 1991, the year of establishment for all firms in our sample, from the current year.

Successful innovation, a firm's ability to come up with new marketable solutions, plays a crucial role in superior business performance (Santarelli and Vivarelli 2007) leading to greater productivity, sales, and profit (Zahra 1996). Empirical investigations suggest that innovation increases firm market value (Hall et al. 2005), and reduces probability of exit (Audretsch 1991; Esteve-Pérez and Mañez-Castillejo 2008; Esteve-Perez et al. 2004; Fontana and Nesta 2010; Huergo and Jaumandreu 2004). On the other hand, innovative activities may impose risks associated with liquidity constraints, inability to capitalize on the research results, lack of patent protection, and others. Several studies find that micro-enterprises are more likely to suffer from negative aspects of innovative activities (Boyer and Blazy 2013; Buddelmeyer et al. 2010; Reid and Smith 2000). In our analysis, we include an indicator variable, *Patents*, which equals one if an establishment has at least one successful patent application between years 1991 and 2008 as reported by the US PTO.

The level of educational attainment in a metropolitan area is a good approximation for the quality of the labor pool and human capital available to businesses in the area. Existing studies show that companies in the regions with a more educated population may face lower (Colombo and Grilli 2007; Headd 2003; Santarelli and Vivarelli 2007; Saridakis et al. 2008), higher, or the same (Arribas and Vila 2007; Nafziger and Terrell 1996; Persson 2004) hazard. Variable *Graduates* is the logarithm of the total number of graduates with a bachelor's degree or higher per 1,000 residents. It is calculated using the Integrated Post-secondary Education Data System files available at http://nces.ed.gov/ipeds/datacenter/. The Data System reports the tally of graduates for each post-secondary educational institution among other indicators. Completions with bachelor's degree or higher are aggregated using locational information to form a MSA-level variable.[10]

Average unemployment in a MSA is a parsimonious measure of metropolitan economic conditions. There is some evidence that bankruptcy rates are lower in Swiss regions with lower unemployment (Buehler et al. 2012). Evidence to the contrary comes from a study of Italian provinces, which finds that on average, firms tend to stay in business longer during the spells of high unemployment (Santarelli et al. 2009). Van Praag (2003) includes both unemployment rate in a region and unemployment status of a firm owner into her analysis. She finds that a business established by an unemployed young person in the US is likely to be short-lived, while unemployment rate does not affect survival chances. We aggregate county-level data provided by the BLS (http://www.bls.gov/lau) into average metropolitan unemployment. A logarithmic transformation of this variable, *Unemployment*, is included in the models.

[9] To ascertain that our estimates do not suffer from multicollinearity, we perform a check suggested by Allison (2010) by regressing regional independent variables on firm age. The VIF statistics for all controls do not exceed 1.03, which is well below 2.5, a conservative 'critical value' that would indicate a multicollinearity problem.

[10] MSAs that have zero graduates are assigned 0.001 graduates (approximately 5 % of the smallest actual number) in order for the logarithm to be determined.

Variable *PopDensity* captures the effect of agglomeration economies, which are believed to facilitate local knowledge spillovers (Griliches 1992; López-Bazo et al. 2004). Empirical research relates presence of agglomerations to economic growth (Rodriguez-Pose and Comptour 2012), increased firm productivity (Lehto 2007), and survival (Acs et al. 2007; Wennberg and Lindqvist 2010). At the same time, high costs of doing business associated with agglomerations (Palazuelos 2005), as well as increased competition, may reduce business survival chances. For instance, in West German regions population density appears to be associated with lower economic growth (Funke and Niebuhr 2005) and higher hazard faced by companies in manufacturing and business services (Brixy and Grotz 2007). We use the logarithm of population density calculated by dividing the estimated MSA population by the land area. The county-level data reported by the US Census Bureau is used for calculations.

To account for industry-specific conditions, a set of dummies (*NAICS3342, NAICS3343, NAICS3344, NAICS3345, NAICS3346*) is included in the models. The computer and peripheral equipment manufacturing (NAICS3341) industry serves as a reference category.

7 Estimation results and discussion

Table 3 presents log-logistic regression estimation results for the whole sample (column 1) and for sub-samples based on the number of firm employees at start-up. Columns (2), (3), and (4) contain results for companies with up to three employees at start-up, four to nine employees, and for all other firms, respectively. All model specifications are statistically significant. The gamma coefficient, which is less than one in all instances, indicates that the log-logistic hazard increases and then decreases, confirming the assumption of exit distribution. Likelihood ratio test that the frailty indicator theta is equal to zero suggests presence of unobserved heterogeneity at the firm level in specifications (1) and (3). The lack of significance in specifications (2) and (4) implies homogenous sub-samples, i.e. the hazard function of individual companies is identical to that of the population (Gutierrez 2002).

The analysis of the whole sample suggests that the perspective of LKS is not supported. Computer and electronic product manufacturing firms face a higher hazard when they are located in more innovative MSAs, according to Model (1). This result is significant at the 10 % confidence level. The coefficient of the variable *Innovation* shows the effect of regional innovative environment on the survival likelihood of companies that have only one employee.[11] The negative relationship between regional innovation and business survival is likely to indicate either an owner's decision to discontinue operation or the presence of creative destruction at the regional level. The positive and significant coefficient of the variable *InnovSize* implies a moderating role played by the firm size. The effect of metropolitan patenting intensity is smaller for the firms that employ more people. This can be explained by greater resourcefulness of larger companies and by their increased ability to counteract the negative effects of unfavorable economic environment in the case of creative destruction. If the higher likelihood of exit in innovative MSAs is the result of choices made by owners, transaction costs provide a possible explanation for a greater propensity of small enterprises to go out of business. Arguably, smaller firms are easier to shut down.

All control variables, except for population density in a metropolitan area, are significant predictors of business survival. In line with the literature, firm age and patenting have strong negative effect on hazard faced by companies in the computer and electronic product manufacturing industry. Firms in more educated metropolitan areas enjoy greater survival likelihood. The level of economic distress measured by the unemployment rate is unsurprisingly associated with increased probability of exit. Conforming to previous studies, industrial characteristics emerge as strong predictors of business survival; all five industry dummies are statistically significant. Companies in computer and peripheral equipment manufacturing face the highest hazard when compared to audio and video equipment manufacturing, semiconductor and other electronic component manufacturing, navigational, measuring, electromedical, and control instruments manufacturing, and manufacturing and reproducing magnetic and optical media.

The estimation by size group reveals somewhat distinct patterns of survival. Companies that start out

[11] The value of variable *Size* in our dataset is zero for such companies. This is because we use a logarithmic transformation of the actual size in our models.

Table 3 Estimation results

Variable	(1) Whole sample[a]	(2) Firms with 1–3 employees at start-up	(3) Firms with 4–9 employees at start-up	(4) Firms with >9 employees at start-up
Innovation	−0.033*	−0.035*	−0.034	0.040
	(0.018)	(0.019)	(0.048)	(0.064)
Size	0.003	0.0144	0.065**	0.027
	(0.010)	(0.019)	(0.028)	(0.023)
InnovSize	0.026***	0.028**	0.033	−0.003
	(0.008)	(0.014)	(0.024)	(0.021)
Age	0.110***	0.106***	0.114***	0.123***
	(0.003)	(0.004)	(0.006)	(0.007)
Patents	0.155***	0.066	0.143***	0.216***
	(0.031)	(0.052)	(0.048)	(0.061)
Graduates	0.025***	0.029***	0.022**	0.013
	(0.006)	(0.011)	(0.010)	(0.012)
Unemployment	−0.299***	−0.230***	−0.254***	−0.364***
	(0.028)	(0.046)	(0.055)	(0.062)
PopDensity	0.004	0.010	0.016	−0.034**
	(0.008)	(0.010)	(0.017)	(0.016)
NAICS3342	0.088***	0.040	0.057	0.120**
	(0.031)	(0.040)	(0.057)	(0.052)
NAICS3343	0.105***	0.101**	0.066	0.017
	(0.039)	(0.049)	(0.078)	(0.066)
NAICS3344	0.122***	0.061*	0.089**	0.164***
	(0.026)	(0.036)	(0.042)	(0.048)
NAICS3345	0.120***	0.062*	0.089**	0.159***
	(0.025)	(0.033)	(0.043)	(0.052)
NAICS3346	0.239***	0.151***	0.236***	0.282***
	(0.032)	(0.040)	(0.059)	(0.099)
Constant	1.650	1.562	1.381	1.915
	(0.077)	(0.095)	(0.145)	(0.177)
# of subjects	1,803	798	630	375
# of observations	19,618	9,472	6,396	3,750
# of exits	853	335	315	203
Gamma	0.163	0.139	0.170	0.182
Theta	0.836	0.623	0.880	0.026
LR test of $\theta = 0$, $\bar{\chi}^2$	11.69	0.89	2.23	0.010
Prob > $\bar{\chi}^2$	0.000	0.172	0.068	0.471
LR χ^2 (13)	490.44	194.06	160.60	166.05
Prob > χ^2	0.000	0.000	0.000	0.000

*** Significant at the 0.01 level; ** significant at the 0.05 level; * significant at the 0.1 level

[a] The sample includes both patenting and non-patenting firms. Recent research shows that innovative and non-innovative enterprises differ in many aspects, including survival dynamics and sensitivity to various factors (Boyer and Blazy 2013). Fitting the survival model using only firms for which *Patents* equals one suggests that survival of such companies depends on industrial characteristics and company age. All other independent variables, including three explanatory ones, are insignificant. In contrast, analysis of non-patenting establishments indicates that firm size promotes survival chances, while innovation in a region increases hazard. The negative effect of external innovation declines as a company grows. Other important factors that promote survival of non-patenting firms include their age and location in MSAs with a high level of educational attainment. Conversely, location in a region with high unemployment and being in NAICS3341 industry is associated with higher hazard for such establishments

with one to three employees are more likely to exit when they are located in MSAs with higher patenting intensity. This result is significant at the 10 % level. Confirming the whole sample results, the interaction term is significant, thus indicating the decrease in hazard as business grows. Variable *Size*, on the contrary, is not statistically meaningful. The survival chances of small firms are positively related to time in business, while patenting activity is not a predictor of longevity. This is in agreement with the literature that reports divergent effects of firm own innovation on the hazard faced by companies of different sizes. Two regional control variables are statistically significant. According to the estimation results, survival likelihood in this sub-sample is higher in more educated metropolitan areas and in regions with lower unemployment. Establishments that started small appear to be less sensitive to industrial characteristics compared to the whole sample. Four industry dummies are significant and two of them are significant at the 10 % confidence level only.

The negative effect of regional innovation on business survival vanishes when medium companies are the focus of analysis. In specification (3), variable *Innovation* is not significant. There is also no evidence of interaction between regional patenting intensity and enterprise size. Company size, nevertheless, is positively related to survival, which substantiates the 'liability of smallness' in this sub-sample. The 'liability of newness' is also supported, as age promotes business longevity. Successful patent applications filed by a medium firm emerge as a strong predictor of survival likelihood. The significance and the coefficients of regional variables are identical to the ones reported for small firms. Finally, the analysis reveals the importance of industrial affiliation; three out of five industrial dummies are statistically significant.

The fact that survival of the firms with more than nine employees at start-up is related to neither innovation nor company size is an important result of this study. It is also consistent with the previous finding of decreasing negative effect of regional innovation on firm survival as companies grow. Age and patenting decrease the hazard faced by large establishments. Noteworthy, the effects of these individual characteristics are amplified as the analysis moves from small to large firms. Large companies in this study turn out to be insensitive to the metropolitan educational attainment. Other regional factors, unemployment and population density, increase hazard faced by establishments with 10 or more employees at start-up. Industrial affiliation plays an important role for the survival likelihood in this sub-sample; four out of five industry indicators are statistically significant.

8 Conclusions

Recent literature suggests an important role played by geographical characteristics as determinants of business survival. This role, however, may depend on company-specific factors. We explored the possibility of interaction between metropolitan innovation and firm size in their effect on firm survival in the US computer and electronic product manufacturing industry during the 1992–2008 period by means of a log-logistic survival regression analysis with frailty shared at the firm level.

The regression results indicate that the relationship between regional patenting activity and the hazard in the computer and electronic product manufacturing industry is positive and significant for the sample as a whole, and for the companies that started with less than four employees in particular. This finding suggests either the presence of a creative destruction regime in the industry of interest, or a higher propensity of business owners to shut down existing firms in order to pursue other ventures. The analysis of the whole sample suggests that the negative relationship between metropolitan innovative environment and business survival in NAICS334 decreases with firm size. The same holds true for small companies. The significance of the interaction term *InnovSize* may imply two possibilities: (1) larger enterprises are less vulnerable to the creative destruction regime, or (2) entrepreneurs in more innovative environments are more likely to re-channel resources by closing existing small firms and opening new companies. Further analysis may identify which scenario holds for the industry. The other two sub-samples analyzed in this study appear to be insensitive to the level of metropolitan innovation. The hazard faced by medium companies decreases with establishment size, while size does not affect survival likelihood of the large firms.

This study confirms the 'liability of newness' for all firm sub-samples. A firm's own innovative activity approximated by at least one successful patent application boosts survival chances for medium and large

companies. It is not significant when the analysis is confined to the establishments that started with one to three employees. In general, the population-adjusted number of college graduates in a MSA decreases hazard faced by NAICS334 firms, while unemployment increases it. Large enterprises tend to exit sooner in metropolitan areas with denser populations.

The findings of this study are of practical relevance to policy-makers who devise and implement economic development programs aimed at new firm formation. Firm formation does not guarantee achieving common goals of economic policies, such as income and employment growth in a region, if newly founded companies exit shortly after entry. Detailed understanding of the process that drives the revealed relationship between metropolitan innovation, firm size, and firm survival would be instrumental for more educated policy design. At the same time, the analysis may prove useful for small business owners and managers as they make location decisions. Small and medium firms need to be aware of the greater hazard faced in actively patenting MSAs, although further research will be instrumental in identifying the actual mechanism behind the observed relationship.

This research offers preliminary insight into the external effects of innovation on business survival. It does not specify the mechanisms behind this dependence. It is plausible to expect that the three potential explanations suggested in this paper operate simultaneously. Separate investigation of these counteracting forces may provide understanding of the reasons for the inability of local knowledge spillovers, if they are present in a region, to translate into increased survival chances for standalone establishments in computer and electronic product manufacturing.

One has to be aware of possible limitations of this analysis. The generalizability of the results may be limited by the focus on only one firm cohort if this cohort happens to be special in its characteristics that determine exit hazard. Future work should study multiple cohorts to identify any dependence on initial conditions. Furthermore, the generalizability of our conclusions remains to be established by repeating this analysis for other industries.

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