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REGULAR ARTICLE

Barriers to innovation in young and mature firms

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Abstract This paper examines how firm age can affect a firm's perception of the obstacles (*deterring* vs. *revealed*) that hamper and delay innovation. Using a comprehensive panel of Spanish firms for the period 2004–2011, the empirical analysis conducted shows that distinct types of obstacle are perceived differently by firms of different ages. First, a clear-cut negative relationship is identified between firm age and a firm's assessment of both the internal and external shortages of financial resources. Second, young firms seem to be less sensitive to the lack of qualified personnel when initiating an innovative project than when they are already engaged in such activities. By contrast, the attempts of mature firms to engage in innovation activity are significantly affected by the lack of qualified personnel. Finally, mature incumbents appear to attach greater importance to obstacles related to market structure and demand than is the case of firms with less experience.

Keywords Barriers to innovation · firm age · probit panel data model

JEL Classifications C23 · O31 · 032 · 033

1 Introduction

According to the Schumpeterian tradition, firm age, along with firm size, is a fundamental factor in determining and differentiating a firm's innovation ability, with the degree of novelty and imitation of its innovation varying significantly over the firm's life course. Indeed, the Austrian scholar in his two most notable works assigns distinct but equally relevant roles to small, newly established and large, mature firms. In Schumpeter Mark I (Schumpeter 1934), new entrepreneurial firms, by investing in R&D and launching new radical innovations favour a renewing process of 'creative destruction'. In contrast, in Schumpeter Mark II (Schumpeter 1942), the main contribution to

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innovation is made by large, more experienced firms, which, by means of a process of 'creative accumulation', represent the main engine of change (see Malerba and Orsenigo 1996; Breschi et al. 2000; Acemoglu and Cao 2010).

Despite the unquestionable influence of Schumpeterian models in innovation studies, surprisingly, much of the related empirical literature has systematically neglected to investigate the relationship between innovation and firm age (with the relevant exceptions of Klepper 1996; Huergo and Jaumandreu 2004[1]). More importantly, there is practically no evidence of the relationship between a firm's evolution and the effects (relevance) that certain firm and market factors can have in hindering its innovative process. Indeed, as would appear to be the norm in the innovation literature, much more emphasis is given to analysing the factors that determine the success of innovation than those that can lead to failure.

In recent years, a new stream of literature has begun to analyse the role played by barriers to innovation in deterring or hampering a firm's innovative efforts (Mohnen and Rosa 2001; Galia and Legros 2004; Segarra-Blasco et al. 2008; Savignac 2008) and to examine the factors affecting a firm's perception of these barriers (Iammarino et al. 2009; D'Este et al. 2012; Hölzl and Janger 2013, 2014). In fact, most have tended to mainly focus on the impact of financial constraints on a firm's innovative behaviour (see Hall 2008 for a review of this subject). Without calling into question the fundamental role played by the availability of internal and external financial resources in determining the firm's innovative decision, other factors have recently been shown to be significant hindrances of a firm's innovative process (see, for example, D'Este et al. 2012; Blanchard et al. 2012; Pellegrino and Savona 2013; Coad et al. 2016a, b). Among these, particular attention needs to be paid to such factors as the shortage of adequate skills, the lack of appropriate information on technologies and on markets, and the lack/uncertainty of demand.

Crucially, the deterrent or hampering effect of these factors can vary over the firm's life cycle: for example, new-born or young firms may be more markedly affected than incumbents by a lack of financial resources or a shortage of adequate skills for the implementation of the innovative process, while the lack/uncertainty of demand might be more of a deterrent to firms with more experience and which, in all probability, operate in highly saturated markets.

Within this context, the main aim of this study is to conduct an empirical investigation of the impact of firm age on a firm's perception of the various obstacles to innovation. Building on the conceptual framework first proposed by D'Este et al. (2012), this relationship is examined by distinguishing between firms that face *revealed* barriers and those that face *deterring* barriers.[2] To do so, univariate and multivariate analyses are undertaken that draw on a large longitudinal dataset of Spanish manufacturing and services firms and which focus on different phases in their life cycles.

Results show that different types of obstacle are perceived differently by firms of different ages. While a clear-cut negative relationship is detected between firm age and both the internal and external lack of financial resources, a less obvious pattern is found

[1] Klepper proposes a theoretical model for studying the evolution in a firm's innovation activities over the industry life cycle. Huergo and Jamandreu empirically examine the way in which the probability of innovation by manufacturing firms changes at different stages in their lives.

[2] The distinction is based on the relationship between the engagement in innovation activity and the perceived importance of constraints to innovation. Deterring barriers prevent firms from engaging at all in innovation activities; revealed barriers are the obstacles that firms face during the innovative process (see Section 2 for a more detailed discussion).

with respect to the other obstacles. Interestingly, young firms, on average, seem to be less sensitive to the lack of qualified personnel when they have to initiate an innovative project than when they are already engaged in innovation activities. Finally, mature incumbents appear to attach greater importance to obstacles related to market structure and demand than is the case of firms with less experience.

The rest of this paper is organised as follows. Section 2 reviews the theoretical and empirical literature examining barriers to innovation and forwards various hypotheses concerning the main research questions. Section 3 provides a detailed description of the dataset and some descriptive evidence. Section 4 presents the empirical strategy and discusses the main results. Section 5 concludes.

2 The literature

2.1 Barriers to innovation

Traditionally, innovation and technological change have been identified as fundamental drivers of aggregate economic growth and development (Solow 1956; Arrow 1962; Griliches 1979). Within this context, most of the empirical literature based on innovation surveys has, in turn, examined the drivers of innovation activities across firms and sectors, while much less importance has been attached to factors that might impede or delay a firm's engagement in innovation.

Yet, within the emerging branch of innovation literature that has begun to turn its attention to the barriers to a firm's innovation activity, two distinct empirical approaches have been adopted. The first has centred its attention on the impact of what are primarily financial barriers on the propensity and intensity of a firm's innovation activity (see Mohnen and Rosa 2001; Savignac 2008; Segarra-Blasco et al. 2008; Blanchard et al. 2012; Pellegrino and Savona 2013), while the second (and comparatively smaller stream in the literature) has focused its attention on analysing firm and market characteristics that can affect a firm's perception of the importance of different types of barrier (Galia and Legros 2004; Iammarino et al. 2009; D'Este et al. 2012; Hölzl and Janger 2013, 2014; D'Este et al. 2014). Here, we seek to contribute to this latter approach and, to this end, the rest of this section examines methodological and conceptual aspects that are crucial to the empirical investigation of the impact of a firm's assessment of the barriers to innovation.

Most empirical studies of innovation barriers report a positive correlation between engagement in innovation and the perception of these barriers. Different explanations have been forwarded to justify this somewhat counterintuitive result. Some authors, for example, interpret this positive link as a signal of a firm's ability to overcome the obstacles to innovation (see Baldwin and Lin 2002; Galia and Legros 2004; Mohnen and Röller 2005). In other words, the more innovative a firm is, the more aware it is likely to be of the obstacles to innovation and so the better equipped it will be to overcome them. Recently, Savignac (2008) has offered a more convincing theory, claiming that the positive spurious correlation between innovation intensity and perception of obstacles can be attributed to an inappropriate selection of the sample used for the empirical analysis. The French scholar suggests restricting analyses to the cohort of so-called 'potential innovators', i.e., those firms that invest in innovation activity (regardless of their success) and those that do not invest but have experienced barriers

to innovation. As demonstrated by later studies (see D'Este et al. 2012; Blanchard et al. 2012; Pellegrino and Savona 2013), this selection procedure is fundamental to ensure consistent results.

Closely related to this concept of potential innovators is the crucial distinction that has been drawn between *revealed* and *deterring* barriers. This important characterisation, first proposed by D'Este et al. (2012), is based on an analysis of the relationship between a firm's engagement in innovation and its assessment of the barriers to innovation. The authors distinguish two types of firm in their sample of potential innovators: those deterred from engaging in innovation activities and those experiencing barriers that obstruct their undertaking innovative projects. In the case of the former, potential innovators may abandon their efforts to innovate as the barriers are insurmountable. Among these obstacles, a key role is played by financial constraints (both internal and external funds), as well as by the lack of qualified personnel or information on technologies and on the market, and uncertainty or lack of demand for innovative products. However, all these factors, apart from preventing a firm from engaging in innovation, can also play a significant role in slowing down its innovative process. In other words, for some firms, the perception of obstacles to innovation may be sufficient to impede/delay (while not prevent altogether) their engagement in innovation. In line with D'Este et al. (2012), such firms can be characterised as experiencing *revealed* barriers to innovation, because their impact is felt once the firm has begun its innovation activity.

Most of the empirical literature to-date however has failed to identify properly the sample of potential innovators and to disentangle the deterring from the revealed barriers to innovation. And as recent contributions stress (see D'Este et al. 2012; Pellegrino and Savona 2013), the conceptual and empirical characterisation of the different types of barrier to innovation and, consequently, of different firm types is fundamental in terms of the broader policy implications. As such, policy interventions might seek to enlarge the population of innovative-active firms (innovation-widening), by removing or alleviating obstacles that prevent firms from engaging in innovation activities; or, alternatively, they might support the existing population of innovative-active firms (innovation-deepening), by removing or alleviating obstacles that prevent the successful completion of innovation projects and hinder adequate returns to innovation investments.

In this paper, building upon D'Este et al. (2012, 2014) and by distinguishing between revealed and deterring barriers, we apply these conceptual frameworks to an examination of the relationship between firm age and a firm's perception of different obstacles to innovation.

2.2 Firm age and barriers to innovation

As discussed in the introduction, no previous studies provide evidence of the impact of age on a firm's perception of the barriers to innovation. Here, our goal is to go some way to filling this gap in the literature by empirically analysing this particular relationship.

Before moving to the empirical part of the paper, by drawing on different streams of organizational and evolutionary literature, we articulate a theoretical framework useful to characterize the nature of the relationship between age and the multiple types of barriers to innovation.

In a seminal study, Stinchcombe (1965) proposed the influential concept of 'liability of newness', according to which young organizations, for their inherent characteristics, may

be in a position of disadvantage with respect to their older counterparts. A critical point of this theory refers to the low level of legitimacy and reputation typical of young organizations. As suggested by the author (ibidem, p. 149), this type of companies needs to learn about the environment in which they operate and gaining legitimacy in the eyes of resource providers, such as finance providers, customers, suppliers and employees (see also Aldrich 1999; Starr and Macmillan 1990; Stuart 2000). The lack of legitimacy and reputation in the financial market is particularly relevant for our discussion. Indeed, newly established or young firms, in contrast with more mature incumbents, cannot rely on their having developed a good reputation on the financial markets, since they will only have built a short-term relationship with the banks and their sources of collateral will be limited (see Petersen and Rajan 1994; Martinelli 1997; Berger and Udell 2002). Moreover, more experienced firms are more likely to be able to rely on their own internal funds, given that they will have accumulated more profits over the years. Accordingly, one can expect young firms to be more sensitive than their more mature counterparts to cost factors when seeking to initiate a new innovation project and when wanting to devote more financial resources to an existing one. The empirical literature generally supports these theoretical expectations. Reid (2003), for example, suggests the existence of an inverse relationship between a firm's age and its debt ratio, while Fluck et al. (1997) show that the ratio between external and total finance tends to fall once a firm has been operating for more than seven or eight years. Schneider and Veuglers (2009) attempted to characterise young, highly innovative companies (firms younger than 6 years and specialising in R&D) and found that such firms appear to perceive the internal and external costs of innovation as being more important than do their mature counterparts.

As suggested by Baum and Oliver (1992), the lack of reputation and legitimacy may be a relevant aspect also in determining the so called 'liability of unconnectedness', which refers to the difficulties of establishing network relationships and which may produce an uneven allocation of the benefits of an alliance in favour of the more established partner (Hill 1990). Baum and Silverman (2004) stress the important role played by a good firm's network position, through which companies may acquire more valuable information about other organizations and their resources, and consequently enlarging the possible choices of partners. Indeed, for alliances to be formed in a network, firms make a first evaluation of each possible partner based on its observed reputation and credibility. The perceived credibility and reputation of a firm is based on its prior achievements, which for newly established or young firms are scarce by definition (see Powell et al. 1996). Accordingly, it would be reasonable to expect a negative relationship between firm age and obstacles related to the difficulties in finding partners for innovation.

A firm's skill endowment is deemed an important driver of its innovative activity (see Leiponen 2005; Piva and Vivarelli 2009) and a skilled workforce is a vital resource for firms dealing with complex activities (including innovation, in general, and R&D, in particular). Cohen and Levinthal (1989, 1990) claim that highly qualified employees are a firm's primary vehicle for absorbing external knowledge and, consequently, for enhancing its absorptive capacity. Florida (2002) argues that a firm's skill base should not be confined to engineering and scientific qualifications, but should incorporate a much wider range of talent (including management, legal and design skills) as each can make a key contribution to creative problem solving.

As suggested by Baron et al. (2002), young firms may have better access to high-skilled employees because of the dynamic and vibrant work environment in which they operate as

compared to their mature counterparts (see also Hannan et al. 1996). Along the same lines, companies with considerable market experience, characterised by well-established organisational routines and production practices, may experience difficulties in adapting and modifying their skills and expertise to change (Nelson and Winter 1982; Hannan and Freeman 1984), especially when seeking to initiate an innovative project. Following the same line of reasoning, this type of companies may also be at a disadvantage when having to identify new technological opportunities. As suggested by Cohen and Levinthal (1990) the ability of a firm to use its accumulated knowledge base for further innovation is extremely dependent upon the patterns of communication and distribution of knowledge within the firms. Thus if aging leads to increased rigidity of communication pattern, firms may have more difficulties in recognising, assimilating and exploiting information vital for the implementation of innovative processes (see also Henderson and Clark 1990).

The inertia and organizational rigidity that characterise more experienced firms might also limit their capacity to react swiftly to changes in demand conditions, in turn making them more sensitive to market barrier factors, especially uncertain demand for innovative goods or services (Nelson and Winter 1982). On the contrary, young firms, which operate in contexts characterised by high level of uncertainty, are generally more inclined to explore new ideas and technologies and consequently less risk adverse than their mature counterparts (Audretsch 1995; Coad et al. 2016a, b). However, according to the Schumpeterian tradition (see Schumpeter 1942; Acs and Audretsch 1988, 1990) less experienced companies can be expected to be less able to exploit the benefits deriving from market concentration and appropriability conditions and, thus, face greater barriers to innovation in markets dominated by established companies.

It is evident from this short discussion that the relationship between firm age and a firm's perception of obstacles to innovation is complex and that it is difficult to hypothesise a clear functional form that captures the exact nature of this relationship. As we see in Section 4, the results of our empirical analyses lend considerable support to these propositions.

3 Data

In this study we draw on firm level data from the Spanish Technological Innovation Panel (henceforth PITEC). PITEC is the result of the joint efforts of the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT), and the Foundation for Technical Innovation (COTEC). The data are collected following the Oslo Manual's guidelines (OECD 1997) and can therefore be considered a Community Innovation Survey or CIS-type dataset. However, one characteristic that distinguishes PITEC from most CIS-type datasets is its panel data structure. Indeed, since 2003, data have been collected systematically, providing highly representative information about the population of Spanish manufacturing and service firms over various time periods. This characteristic represents an important methodological advantage as it allows us to control for unobserved heterogeneity.

In addition to detailed information about a firm's general characteristics (including, main industry of affiliation, turnover, employment, founding year, etc.), PITEC collects data related to a large set of innovation-related aspects: assessments of engagement in innovation activity, economic and non-economic measures of the effects of innovation, self-reported evaluations of factors hampering or fostering innovation, participation in

cooperative innovation activities and complementary innovation activities such as organisational change and marketing.[3]

In this paper, we draw on 8 consecutive waves from 2004 to 2011.[4] The initial sample, comprising 100,016 annual observations (around 12,000 firms every year), was selected according to the following procedure. First, we excluded those firms operating in the primary (1628 observations), construction (3914 observations), utilities (720 observations) and sewage/refuse disposal (318 observations) sectors and those firms engaged in processes of mergers or acquisitions (8543 observations).[5] Additionally, given the presence of missing values for the variables employed in the empirical specification (see Section 4.2.1), a further 15,289 observations were ruled out.

In line with the discussion presented above (Section 2), we retained in our sample only the 'Potential Innovators'. In other words, we excluded those firms that, by inference, can be defined as 'Non innovation oriented firms'. This filtering procedure enabled us to correct a clear anomaly that characterises the design of the CIS questionnaire, whereby all firms (regardless of their willingness to innovate) are asked to respond to the questions regarding obstacles to innovation. More specifically, we excluded 6943 observations referring to firms that did not engage in any of the seven innovation activities specified in the questionnaire (see Table 8 in the Appendix) and which, at the same time, did not experience any barriers to innovation during the period under analysis (see Table 9 in the Appendix).[6,7] Thus, we ended up with a sample comprising 62,661 firm-year observations.

Table 1 present the composition of this unbalanced panel taking into account the number of years a given firms is observed. As can be seen, more than 40% of the firms is observed over the entire sample period, 23% for 7 years, and only a marginal percentage (11,83%) for less than 4 years.

In line with our main research questions, among the potential innovators, we need to distinguish those firms that face deterring barriers from those that face revealed barriers to innovation. Following D'Este et al. (2012, 2014), the former can be identified as those companies that declare no engagement in innovation activity and yet to having faced at least one barrier item, while the latter comprises those firms that have faced at least one barrier item and which claim involvement in at least one of the seven innovation activities.[8] Thus,

[3] Recent studies using this dataset include López-García et al. (2013), D'Este et al. (2014) and Segarra and Teruel (2014).

[4] Following the design of the CIS questionnaire, PITEC data is collected retrospectively over a three year period. This specific characteristic of the dataset may cast doubts about the accuracy of the longitudinal information we use for the empirical analysis. Accordingly, as a robustness check, we estimate equation (1) using a restricted dataset obtained by considering exclusively 3 (not overlapped) waves, namely 2011, 2008 and 2006. The results – available upon request – are not qualitatively different from those reported in Tables 5, 6 and 7.

[5] These firms were eliminated from the sample in the years following the merger or acquisition.

[6] As the proposed definition suggests, potential innovators are firms that are willing to innovate, and that either manage to engage in one of the seven innovation activities or fail in their attempt to do so, supposedly due to the effect (among other factors) of the obstacles to innovation they encounter.

[7] One may be concerned about the potential problem of sample selection caused by this exclusion procedure, particularly if the age distribution of the sample of not innovation oriented firms considerably differs from that one of the selected sample. However, this does not seem to be case in this study. Indeed, the average age of the sample of not innovation oriented firms is 25.33 (standard deviation 17.16) slightly higher than that one of the selected sample (24.93 with a standard deviation of 20.20).

[8] Note that the only difference between the two groups concerns the respective degree of engagement in innovation activity.

within the total sample, we identify 43,046 observations referring to firms facing revealed barriers and 18,140 observations referring to firms facing deterring barriers to innovation activity.[9]

4 Empirical analysis

4.1 Firms' perception of barriers to innovation along their life course

In this section we provide preliminary univariate evidence for our main research question. Specifically, we use lowess smoothing techniques to obtain non-parametric estimations of the impact of age on a firm's perception of the various obstacles to innovation. Following the PITEC questionnaire design (see Table 8 in the Appendix), we study this relationship by considering three different barrier factors: 1) cost; 2) knowledge; and 3) market, and a total of nine barrier items. However, we focus our attention on just seven of these after excluding the cost factor of 'direct innovation costs too high', and by collapsing two knowledge barrier items into one, namely 'lack of information on technology' and 'lack of information on markets'.[10]

Before discussing the results of the non-parametric analysis, it is useful to report some general insights from the firms' evaluation of barriers to innovation. Table 2 shows the proportion of firms (full sample and the two sub-samples) assessing each of the seven barrier items as highly important. In the case of the total sample, cost factors are, as expected, the category that presents the highest percentages (always above 30%), while market factors are, in general, deemed more important than knowledge factors. As for the two sub-samples, the proportion of firms facing deterring barriers that assess the obstacles to innovation as highly important is always higher than those facing revealed barriers. In line with the evidence provided in D'Este (2012), these figures confirm the importance of taking into account the different nature of the barriers firms face. This would appear to be particularly true for the following barrier items: 'lack of internal funds', 'lack of qualified personnel' and 'uncertain demand for innovative products'.

Figures 1, 2 and 3 in the Appendix illustrate the results of the lowess estimations obtained when considering the total sample of firms. As can be seen, the only factor that shows a clear overall linear trend is the cost factor, with the two barrier items (lack of internal and external funds) showing a monotonic decreasing relationship with firm age. The knowledge factor presents a less clear-cut pattern. Of the three barrier items considered, only one ('difficulties in finding partners for innovation') presents a negative (albeit not particularly marked) relationship with age. In the case of the market factors, a U-shaped relationship is detected for the item 'market dominated by established firms', with

[9] These figures do not, however, add up to 62,661. Indeed, there are 1457 firm-year observations that declare involvement in innovation activity but which did not experience any kind of barrier to innovation. Since a firm's innovation activity is central to this paper, we decided not to exclude these firms and to perform our empirical analyses considering both the total sample and the two sub-samples of firms.

[10] We opted to exclude the cost barrier item as it is redundant when considered alongside the other two cost barriers. The same rationale applies to the decision to consider the variables related to lack of information on technology and market jointly.

Table 1 Composition of the panel

Time obs.	N° of firms	%	% Cum.	N° of obs.
1	370	3.80	3.80	370
2	366	3.76	7.57	732
3	414	4.26	11.83	1242
4	533	5.48	17.31	2132
5	679	6.98	24.29	3395
6	938	9.65	33.93	5628
7	2238	23.01	56.95	15,666
8	4187	43.05	100	33,496
Total	9725	100		62,661

a decreasing relationship being recorded until around a firm's sixtieth year and with mature firms appearing particularly sensitive to this barrier item. This trend is not, however, observed for the second market item 'uncertain demand for innovative products', where the curve describing its relationship with age is practically flat.

4.2 Impact of age on firm's perception of barriers to innovation: a multivariate analysis

4.2.1 Variables and econometric methodology

In the two subsections that follow, we investigate further the preliminary evidence discussed above by undertaking multivariate analyses that allow us to determine the impact of firm age on the firm's perception of obstacles to innovation after controlling for observed and unobserved factors.

For the univariate analysis, we consider seven binary indicators as dependent variables, each identifying firms that assess the selected cost, knowledge and market barriers as highly important. Each of these factors is regressed on a set of control variables and on a set of dummy variables identifying different age classes. Specifically, in selecting the different age thresholds, we sought to represent the different phases in the firm's life course while avoiding any great disparities (in terms of the number of firms) across the different age categories. Thus, we selected the following five age classes: from 1 to 8 years, from 9 to 20 years, from 21 to 30 years, from 31 to 50 years, and more than 51 years.[11]

Table 3 shows the composition of the different samples by age category, while Fig. 4 in the appendix shows the proportion of firms that assess the seven obstacles as highly important by age category and by sub-sample (i.e., revealed vs. deterring). In line with the results from the non-parametric estimations, a clear negative relationship is found between firm age and a firm's perception of cost barriers to innovation, with a notable difference being recorded between the percentages reported by the first and last age

[11] In selecting the cut-off for the first age class we referred to recent contributions that, in order to identify and explore the innovative peculiarities of young companies, use a threshold of 8 years (see Pellegrino et al. 2012, and García-Quevedo et al. 2014; see also van Praag and Versloot, 2007). Robustness checks were performed assuming alternative thresholds or different age groups. Results – available upon request – are consistent (both in terms of the sign and statistical significance of the estimated coefficients) with those discussed in Section 4.2.2.

Table 2 Proportion of firms assessing obstacles to innovation as highly important

	Total	Deterring	Revealed	Mean comp. Test	
Cost obst.(int.)	0.33	0.36	0.33	0.02***	(5.09)
Cost obst.(ext.)	0.32	0.31	0.33	−0.02***	(−5.09)
Know obst.(skill)	0.12	0.15	0.11	0.04***	(11.61)
Know obst.(info.)	0.13	0.13	0.12	0.01**	(2.61)
Know obst.(coop.)	0.12	0.14	0.12	0.02***	(6.83)
Mkt. obst.(incum.)	0.20	0.21	0.20	0.01	(1.52)
Mkt. obst.(demand)	0.23	0.26	0.23	0.03***	(8.06)
Observations	62,661	18,140	43,046		

categories. In contrast, the differences between the five age classes are much less marked for the other two barrier factors. Interestingly, and in line with the theoretical discussion previously proposed (see Section 2.2), in the case of firms facing deterring barriers, the market factor 'uncertain demand for innovative goods' appears to be more relevant for more experienced firms than for those in the early stages of their life.

Apart from these five age classes, we consider other control variables that may affect the firm's perception of the different obstacles to innovation. The choice of these additional controls was made taking into account both the information obtained from the questionnaire and the main insights provided in the literature.

First, we control for firm size by taking the natural logarithm of a firm's total number of employees. Previous evidence shows that larger firms are less sensitive to barriers to innovation than are their smaller counterparts (see D'Este et al. 2012; D'Este et al. 2014). Indeed, large companies are able to rely more fully on internal funds, enjoy easy access to external funds and a high level of appropriability and are able to exploit economies of scale; all of which are important in alleviating the negative impact of obstacles to innovation (Schoonhoven et al. 1990; Katila and Shane 2005). Since, these same favourable effects may apply to firms that form part of an industrial group (see Mairesse and Mohnen 2002), we include a variable that identifies such enterprises.

Second, we control for the degree of internationalisation achieved by a firm by considering a variable that is equal to 1 if the firm's most significant destination market is international and 0 otherwise. As D'Este et al. (2012) show firms operating in foreign countries may be less affected by knowledge-related obstacles to innovation as a result of the so-called learning-by-exporting process (see Clerides et al. 1998), but more affected by market-related obstacles as they are exposed to fiercer competition.

We also control for appropriability conditions, by identifying those firms that make use of patents and informal methods to protect their innovations. In addition, we include a dummy variable equalling 1 if the firm indicates that it received any kind of public financial support for innovation activities from Spanish local or government authorities and from the EU bodies, including tax credits or deductions, grants, subsidized loans, and loan guarantees. Previous evidence generally shows a positive association between access to public support of innovation and a higher importance of the barriers to innovation, in particular when the focus is on revealed barriers. As pointed by D'Este et al. (2014) this positive relationship might suggest that public

Table 3 Composition of the different samples by age category

Firm age (years)	Total sample		Deterring		Revealed	
	Freq.	%	Freq.	%	Freq.	%
1–8	7844	12.52	1544	8.51	6124	14.23
9–20	24,359	38.87	7774	42.86	16,061	37.31
21–30	14,132	22.55	4654	25.66	9147	21.25
31–50	11,420	18.23	3046	16.79	8084	18.78
>51	4906	7.83	1122	6.19	3630	8.43
Total	62,661	100	18,140	100	43,046	100

funding schemes are more likely to be oriented to supporting firms that are already engaged in any innovative project (see also Wallsten 2000).

Finally in order to check for possible macroeconomic trends and for sectoral peculiarities we also consider a set of industry and year dummies.

Table 4 shows the descriptive statistics (mean and standard deviation) for the above variables for the pooled sample and for the two sub-samples of firms facing deterring or revealed barriers, respectively. As expected, the two groups of firms present some notable differences. Specifically, firms that have experienced revealed obstacles are much more oriented to foreign markets, more likely to use formal and informal methods of protection and present a higher probability of receiving public subsidies than firms that have experienced deterring barriers. All in all, these descriptive statistics further corroborate the importance of taking into account the different nature of the barriers firms face.

In order to verify how the above variables might affect a firm's assessment of the barriers to innovation we estimate the following equation:

$$Y_{jit} = I\left[\beta' X_{it} + \sum \delta_k' Age_{kit} + c_i + \varepsilon_{it} > 0\right] \quad (1)$$

where $I[\cdot]$ is an indicator function that takes a value of 1 if the argument in brackets is true, and zero otherwise, Y_{jit} ($j = 1,\ldots 7$) denotes the seven binary obstacle variables, X_{it} is the vector of control variables described above, Age_{kit} ($k = 1,\ldots 5$) represents the set of dummies identifying the five age categories, c_i is the unobserved time-invariant individual effect, and ε_{it} an idiosyncratic error term.

Equation (1) is estimated by applying a standard random effect probit model.[12] As is standard, to avoid the dummy trap problem associated with the inclusion of the set of age dummies a reference category should be dropped, its effect on the dependent variables being captured by the intercept. However, in the case of more than one set

[12] Alternatively we could have considered a fixed effect specification. However, due to the small degree of variation in the dependent variables, the use of this econometric model would have notably reduced the sample of firms considered for analysis. Indeed, on average, a considerable percentage of firms experiencing any of the seven obstacles to innovation considered in any year t, retain this status in t + 1. In particular, this percentage ranges from 68% in the case of the obstacle barrier item labelled 'uncertain demand for innovative goods/services' to 78% in the case of the obstacle 'Lack of available finance within the firm'. Therefore, we preferred to have a larger (and more representative) sample and implement random effects only.

Table 4 Descriptive statistics (mean, sd) for the pooled sample and for the two sub-samples

	Total sample		Deterring		Revealed	
	Mean	SD	Mean	SD	Mean	SD
Foreign markets	0.63	0.48	0.48	0.50	0.70	0.46
Industrial group	0.36	0.48	0.31	0.46	0.38	0.48
Informal protection	0.24	0.42	0.11	0.31	0.29	0.46
Patent	0.12	0.33	0.02	0.14	0.17	0.38
ln(Size)	4.09	1.56	4.05	1.67	4.08	1.50
Subsidy	0.36	0.48	0.05	0.22	0.49	0.50
Observations	62,661		18,140		43,046	

of mutually exclusive dummies,[13] the intercept captures the aggregate effect of all the excluded dummy variables, so that the separate effects of the various excluded dummy variables cannot be estimated. Further, the results of the estimations are sensitive to the choice of the 'left-out' reference category. Taking into account that the effect of firm age is central to our analysis, to deal with these problems we use the well-known methodology proposed by Suits (1984). According to this simple approach, once the equation has been estimated, a value k can be chosen and added to each of the coefficients of the age dummies and subtracted from the constant term (including of course the zero coefficient of the 'left-out' age category).[14] The effect of each age category can thus be interpreted as a deviation from the average age effects.

4.2.2 Results

Tables 5, 6 and 7 show the econometric results of the random effect probit model for the total sample and the two sub-samples of firms experiencing deterring and revealed barriers to innovation.[15]

The most obvious outcome reported in Table 5 (total sample) is the negative relationship between firm age and a firm's assessment of the cost factor. Indeed, in line with the discussion above (see Section 2.2), young firms (up to 20 years) report the lack of internal and external financial resources a significant obstruction to their innovative activity, whereas firms in the last three age categories appear to be considerably less hampered by these barrier items. This evidence is even more pronounced if we look at the magnitude of the coefficients of the 5 age categories, which show a clear-cut monotonic decrease. In particular, it is worth noticing the considerable difference in magnitude between the coefficients of the first and the second age class, with the former being four times greater than the latter. Interestingly enough, comparing the results of Tables 6 and 7, it emerged that the youngest group of firms are particularly

[13] The econometric specification includes a set of eight time and 34 industry dummies.

[14] The value k is chosen so that the new age dummy coefficients average zero. Estimating the equation with all the age dummies and this restriction would produce identical statistical properties as the original estimation (see Suits 1984, for more details).

[15] As a robustness check, in order to control for any correlation among the error terms of the regressors for the different obstacle variables we implement a multivariate probit regression. The results, available upon request, are in line with those reported in Tables 5, 6 and 7.

Table 5 Probit random effect estimations for the whole sample

	(1) Cost.(int.)	(2) Cost.(ext.)	(3) Know.(skill)	(4) Know.(info)	(5) Know.(coop)	(6) Mkt.(incum.)	(7) Mkt.(uncer.)
1–8	0.258***	0.216***	0.031	0.042	0.049	0.051	−0.026
	(0.031)	(0.030)	(0.039)	(0.038)	(0.035)	(0.034)	(0.031)
9–20	0.065***	0.054***	−0.007	0.043	−0.015	−0.009	−0.038
	(0.021)	(0.020)	(0.026)	(0.026)	(0.024)	(0.023)	(0.020)
21–30	−0.084***	−0.069***	0.016	0.042	−0.013	−0.017	−0.020
	(0.023)	(0.022)	(0.029)	(0.028)	(0.027)	(0.025)	(0.022)
31–50	−0.132***	−0.088***	−0.040	−0.059*	−0.005	−0.047	−0.012
	(0.029)	(0.028)	(0.035)	(0.035)	(0.033)	(0.031)	(0.027)
>51	−0.106***	−0.114***	−0.000	−0.068	−0.017	0.022	0.097**
	(0.047)	(0.045)	(0.057)	(0.056)	(0.052)	(0.050)	(0.044)
Foreign markets	0.039	0.100***	−0.105***	−0.014	−0.034	0.025	0.046*
	(0.025)	(0.025)	(0.032)	(0.031)	(0.029)	(0.028)	(0.025)
Industrial group	−0.232***	−0.218***	−0.268***	−0.187***	−0.259***	−0.171***	−0.140***
	(0.029)	(0.028)	(0.036)	(0.035)	(0.033)	(0.031)	(0.028)
Informal protection	0.074***	0.107***	0.078***	0.076***	0.064**	0.077***	0.087***
	(0.022)	(0.022)	(0.028)	(0.028)	(0.027)	(0.024)	(0.022)
Patent	−0.001	0.066**	−0.012	0.052	0.133***	0.018	0.009
	(0.030)	(0.029)	(0.039)	(0.037)	(0.036)	(0.033)	(0.030)
ln(Size)	−0.247***	−0.184***	−0.085***	−0.107***	−0.138***	−0.107***	−0.133***
	(0.012)	(0.011)	(0.014)	(0.014)	(0.013)	(0.012)	(0.011)
Subsidy	0.042**	−0.052***	−0.032	0.103***	0.018	−0.006	0.021
	(0.020)	(0.019)	(0.026)	(0.025)	(0.024)	(0.022)	(0.020)
Constant	0.161	−0.113	−1.779***	−1.743***	−1.193***	−1.293***	−1.278***
	(0.101)	(0.095)	(0.122)	(0.120)	(0.106)	(0.110)	(0.099)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sectoral Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	62,661	62,661	62,661	62,661	62,661	62,661	62,661
lnL	−29,342.81	−29,902.75	−17,563.16	−17,922.78	−18,495.99	−24,000.03	−27,260.02
Sigma	1.389***	1.288***	1.396***	1.374***	1.222***	1.373***	1.214***

Table 5 (continued)

	(1) Cost.(int.)	(2) Cost.(ext.)	(3) Know.(skill)	(4) Know.(info)	(5) Know.(coop)	(6) Mkt.(incum.)	(7) Mkt.(uncer.)
	(0.019)	(0.017)	(0.025)	(0.024)	(0.022)	(0.021)	(0.017)
Rho	0.659***	0.624***	0.661***	0.654***	0.599***	0.653***	0.596***
LR test rho	16,051.335	14,465.923	9457.699	9564.103	7779.108	13,021.988	11,610.164
p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes; ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively. Standard errors in brackets. Time and industry dummies are included

Table 6 Probit random effect estimations for the sample of firms experiencing deterring barriers to innovation

	(1) Cost.(int.)	(2) Cost.(ext.)	(3) Know.(skill)	(4) Know.(info)	(5) Know.(coop)	(6) Mkt.(incum.)	(7) Mkt.(uncer.)
1–8	0.349***	0.263***	−0.160**	−0.049	−0.011	0.067	−0.061
	(0.059)	(0.058)	(0.072)	(0.073)	(0.069)	(0.063)	(0.059)
9–20	0.030	0.037	−0.020	0.014	0.025	−0.072**	−0.061*
	(0.036)	(0.036)	(0.044)	(0.045)	(0.042)	(0.040)	(0.036)
21–30	−0.088**	−0.059	0.011	−0.007	0.016	−0.067	−0.002
	(0.041)	(0.040)	(0.049)	(0.050)	(0.047)	(0.044)	(0.040)
31–50	−0.156***	−0.156***	−0.062	−0.032	−0.011	−0.055	0.059
	(0.050)	(0.049)	(0.060)	(0.062)	(0.058)	(0.055)	(0.049)
>51	−0.136*	−0.085	0.231***	0.074	−0.019	0.128	0.065
	(0.081)	(0.079)	(0.093)	(0.099)	(0.094)	(0.086)	(0.078)
Foreign mkt	0.035	0.096**	−0.133**	−0.085	−0.020	−0.035	0.097**
	(0.044)	(0.044)	(0.054)	(0.056)	(0.051)	(0.049)	(0.044)
Ind. Group	−0.463***	−0.436***	−0.433***	−0.415***	−0.486***	−0.375***	−0.385***
	(0.052)	(0.051)	(0.065)	(0.067)	(0.062)	(0.058)	(0.052)
Inf.Prot.	0.007	0.056	−0.004	0.002	0.001	−0.056	0.087
	(0.056)	(0.055)	(0.069)	(0.071)	(0.068)	(0.062)	(0.056)
Patent	−0.009	0.117	−0.299*	−0.197	−0.058	−0.053	−0.216*
	(0.111)	(0.108)	(0.153)	(0.151)	(0.139)	(0.129)	(0.115)
ln(Size)	−0.211***	−0.159***	−0.067***	−0.089***	−0.119***	−0.058***	−0.134***
	(0.018)	(0.017)	(0.021)	(0.022)	(0.020)	(0.019)	(0.018)
Subsidy	0.040	−0.117*	0.008	0.195**	0.051	0.068	0.082
	(0.068)	(0.068)	(0.086)	(0.086)	(0.082)	(0.077)	(0.068)
Constant	0.304**	−0.119***	−1.509***	−1.470***	−1.299***	−1.349***	−1.046***
	(0.148)	(0.145)	(0.182)	(0.185)	(0.170)	(0.169)	(0.151)
Year D.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sect. D.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	18,140	18,140	18,140	18,140	18,140	18,140	18,140
lnL	−9141.34	−8975.99	−6009.37	−5621.47	−6042.00	−7517.59	−8593.64
Sigma	1.392***	1.329***	1.441***	1.454***	1.309***	1.435***	1.288***
	(0.035)	(0.034)	(0.044)	(0.047)	(0.042)	(0.040)	(0.034)
Rho	0.659***	0.638***	0.675***	0.679***	0.631***	0.673***	0.624***
LR test rho	3436.704	3059.805	2573.406	2357.487	1967.900	3055.102	2862.483
p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes; ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively. Standard errors in brackets. Time and industry dummies are included

sensitive to the deterring *vs* revealed effect of the cost obstacles. Indeed, although always highly significant, the coefficients of the first age class (1 to 8 years) appear to be substantially higher in magnitude for the subsample of firms experiencing deterring barriers to innovation.[16] Besides demonstrating the importance of distinguishing between different groups of firms when analysing barriers to innovation, these results, which are in line with previous research on the subject (see Schneider and Veugelers 2010), confirm our hypothesis that newly created firms tend to perceive the internal and external cost of innovation as more important than do their mature counterparts.

An interesting relationship is also found between firm age and the barrier item labelled 'lack of qualified personnel'. The parameter estimates in column 3 of Table 6 show that this knowledge factor is perceived as being significantly less important in deterring engagement

[16] The result of a z-test (1.71) confirms that this difference is statistically significant at the 10% level.

Table 7 Probit Random Effect estimations for the sample of firms experiencing revealed barriers to innovation

	(1) Cost.(int.)	(2) Cost.(ext.)	(3) Know.(skill)	(4) Know.(info)	(5) Know.(coop)	(6) Mkt.(incum.)	(7) Mkt.(uncer.)
1–8	0.227***	0.200***	0.088*	0.046	0.059	0.041	−0.031
	(0.039)	(0.037)	(0.047)	(0.046)	(0.043)	(0.041)	(0.038)
9–20	0.106***	0.075***	−0.000	0.048	−0.028	−0.002	−0.029
	(0.027)	(0.025)	(0.033)	(0.032)	(0.030)	(0.029)	(0.025)
21–30	−0.099***	−0.087***	0.037	0.080**	−0.039	−0.043	−0.049*
	(0.030)	(0.028)	(0.037)	(0.035)	(0.034)	(0.032)	(0.028)
31–50	−0.144***	−0.071**	−0.025	−0.082**	0.000	−0.051	−0.028
	(0.037)	(0.034)	(0.044)	(0.043)	(0.040)	(0.039)	(0.034)
>51	−0.090	−0.117**	−0.099	−0.092	0.008	0.054	0.138***
	(0.059)	(0.055)	(0.070)	(0.068)	(0.063)	(0.060)	(0.053)
Foreign markets	0.047	0.119***	−0.083**	0.009	−0.013	0.061*	0.027
	(0.033)	(0.031)	(0.041)	(0.040)	(0.037)	(0.036)	(0.032)
Industrial group	−0.172***	−0.165***	−0.196***	−0.109**	−0.192***	−0.102***	−0.064*
	(0.036)	(0.034)	(0.045)	(0.043)	(0.041)	(0.039)	(0.035)
Informal protect.	0.082***	0.102***	0.116***	0.104***	0.085***	0.100***	0.091***
	(0.026)	(0.025)	(0.034)	(0.032)	(0.031)	(0.028)	(0.026)
Patent	−0.009	0.068**	0.011	0.089**	0.156***	0.038	0.030
	(0.033)	(0.032)	(0.043)	(0.040)	(0.039)	(0.036)	(0.033)
ln(Size)	−0.277***	−0.213***	−0.088***	−0.136***	−0.139***	−0.148***	−0.143***
	(0.016)	(0.015)	(0.019)	(0.018)	(0.017)	(0.016)	(0.015)
Subsidy	0.065***	−0.062***	0.024	0.119***	0.075***	0.036	0.058**
	(0.024)	(0.023)	(0.031)	(0.030)	(0.028)	(0.026)	(0.024)
Constant	0.285**	0.145	−2.000***	−1.882***	−1.215***	−1.222***	−1.400***
	(0.132)	(0.123)	(0.160)	(0.158)	(0.136)	(0.143)	(0.130)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sectoral Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	43,046	43,046	43,046	43,046	43,046	43,046	43,046
lnL	−20,045.61	−20,699.53	−11,526.93	−12,275.36	−12,412.60	−16,362.09	−18,426.70
Sigma	1.553***	1.420***	1.515***	1.476***	1.321***	1.503***	1.320***

Table 7 (continued)

	(1) Cost.(int.)	(2) Cost.(ext.)	(3) Know.(skill)	(4) Know.(info)	(5) Know.(coop)	(6) Mkt.(incum.)	(7) Mkt.(uncer.)
	(0.026)	(0.023)	(0.033)	(0.031)	(0.028)	(0.028)	(0.023)
Rho	0.707***	0.669***	0.697***	0.686***	0.636***	0.693***	0.635***
LR test rho	11,728.104	10,727.916	6294.189	6699.466	5376.083	9419.943	8321.637
p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes; ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively. Standard errors in brackets. Time and industry dummies are included

in innovation among those firms in the early stages of their life (1 to 8 years) than it is among those firms with ages around the sample mean. In contrast, the only category of firms for which the lack of qualified personnel is regarded as a relevant deterrent to their innovative efforts are those in the last age category (more than 51 years). In this case, in fact, the coefficient of this variable appears to be positive significant and considerably high in magnitude. In line with the theoretical discussion put forward in Section 2.2, this result suggests that mature firms (typically characterised by well-established organisational and production practices) are at a disadvantage when it comes to reorganising themselves and adopting the skills and expertise required to initiate a new innovative project. New-born and young companies, on the other hand, that enter the market with an innovative idea seem to consider themselves to be well-equipped in terms of skilled workers and human capital. Different results, however, are detected among the sample of firms facing revealed barriers to innovation. In this case, while the parameter for firms in business for more than 51 years is no longer significant, a positive (albeit barely significant) association between the youngest firms (1 to 8 years) and the barrier item 'lack of qualified personnel' is detected. All in all, these results seem to suggest that mature firms, in contrast to their younger counterparts, are more able to properly assess the extent to which their workforce is sufficiently skilled and properly trained to successfully carry out an innovative project. According to this interpretation, mature firms may decide to not engage in specific innovation activity because aware of their workforce's lack of adequate skills and expertise. In contrast, young firms, for their inherent characteristics, may be more prone to overestimate the actual ability of their workforce to carry out a new innovative project, and realize only at a later phase that they actually do not possess suitable personnel.

In the case of the two market factors, the only notable result is the highly significant association between firms in the last age category facing revealed barriers and the barrier item labelled 'uncertain demand for innovative goods/services'. In particular, the high magnitude of the coefficient clearly demonstrates how relevant is the impact of type of obstacles in hampering the innovative activity of the most experienced firms. Once again, this evidence corroborate the proposed theoretical framework: more experienced firms, being characterised by an high level of organizational rigidity and inertia, are less capable then their younger counterparts to react swiftly to changes in demand conditions and to operate efficiently in context characterized by an high level of uncertainty (see Henderson and Clark 1990; Coad et al. 2016a, b).

As for the other firm characteristics, large firms and firms belonging to an industrial group appear, as expected, to perceive the various obstacles to innovation as being less relevant than do their counterparts. In addition, the 'subsidy' variable is mainly positive and significantly correlated with a greater degree of importance being attached to revealed barriers to innovation. This result is in line with previous evidence (see D'Este et al. 2014) and it may be related to the fact that public supports to innovation are more likely to benefit firms that are already engaged in innovation activity.

No effects are detected among firms facing deterring barriers in relation to appropriability conditions. However, in contrast with previous evidence (see D'Este et al. 2014), both patent and informal protection appear to be positively associated with higher levels of relevance of the various obstacle items in the case of firms facing revealed barriers.

Finally, in line with D'Este et al. (2012), firms with a greater foreign market orientation seem not to suffer so greatly the effects of a 'lack of qualified personnel', indicating perhaps the beneficial effects of learning from direct experience of the

exporting mechanism. Interestingly, these firms seem to be more strongly affected than their counterparts by the lack of external funds.

5 Conclusions

The main objective of this article was to empirically investigating the impact of firm age on the perception of obstacles to innovation. By building on a theoretical framework first proposed by D'Este et al. (2012), this specific relationship has been investigated by distinguishing between firms that face either revealed or deterring barriers. In so doing, we have performed both univariate and multivariate analyses of a large representative sample of Spanish manufacturing and services firms for the period 2004–2011.

Our results, in addition to confirming the need to distinguish between deterring and revealed barriers, show that different obstacle types are perceived differently by firms of different ages.

First, a clear-cut negative relationship has been identified between firm age and a firm's assessment of both the internal and external shortage of financial resources, especially in the group of firms facing revealed barriers to innovation. As such, this result confirms the importance of policy interventions that seek to finance the innovative projects of newly created firms, but at the same time it points to the need for policy schemes that can financially sustain firms already engaged in innovation activity and that have recently entered the market (less than 20 years ago). In particular, specific attention should be devoted to programmes geared towards the promotion of remarkably risky projects conducted by young innovative companies. Public authorities should spur the creation and diffusion of some form of private financial intermediation, most notably Venture Capitalists. The complementarity between private and public risk financing is a particularly important objective for policy makers to consider as our results have shown the importance of access to finance hampering young firm's innovative activities. Such mixed interventions could be desirable in order to render the policy instruments more effective and to avoid usual deadweight and substitution effects.

Another result stemming from the econometric analysis, points to some dissimilarities in the level of perception of the knowledge obstacle 'lack of qualified personnel' of firms of different ages. In this respect, firms in the early stages of their life seem to be less sensitive to this type of obstacle when having to initiate an innovative project, but more markedly affected by an obstacle of this type when already engaged in innovation activities. In contrast, mature firms appear to attach greater importance to this specific knowledge obstacle when having to initiate a new innovative project. It would seem that this outcome might be linked to the organisational rigidity and structured routines that come to characterise incumbents and which might lead to a certain degree of resistance when having to adjust staff skills and expertise. Another interpretation may be related to the different level of ability of firms of different ages to assess the extent to which their workforce is sufficiently skilled and properly trained to successfully carry out an innovative project. According to this interpretation, mature firms may decide to not engage in specific innovation activity because aware of their workforce's lack of adequate skills and expertise. On the other hand, young firms may be more prone to overestimate the actual ability of their workforce to carry out a new innovative project, and realize only at a later stage that they actually do not possess suitable personnel.

These findings clearly suggest the need to contrast different systemic failures associated with deficiency in terms of education, training and human capital that affect different types of firms at different stages of their life. Accordingly, along with long-term structural policies aimed at improving the educational level of a country and its higher education system, more targeted policies should be set in order to address specific issues. This includes, for example, financial support and tax incentives for training employees and policies aimed at improving the interactions between firms and public research centres. In accordance with our results, such programmes should be designed to sustain in particular new born innovative companies and firms at the mature stage of their life that want to start a new innovative project.

Finally, from the empirical evidence, it seems that mature firms attach greater importance to obstacles related to market structure and demand than is the case of firms with less experience. These findings seem to confirm the relevance of demand as a crucial incentive to innovation, specifically for established firms. In this respect, concrete policies may be put forward in order to boost consumption and enhancing market's reaction to the introduction of new products. The range of instruments that can be implemented in order to reach this goal is ample. Along with the different types of the traditional public procurement schemes, mainly directed at encouraging a broader demand, more focused programmes that are specifically oriented towards private demand should be put into practice. Government or public institutions could, for example, promote price-based measures in the form of demand subsides and specific policies aimed ad directly reducing prices of certain innovative products. Along the same lines, labelling and information campaigns could be implemented in order to enhance the awareness for an innovation and security for its use, in turn accelerating its diffusion. Other possible measures could go in the directions of improving user involvement in innovation production (user-driven), or defining new functional requirements for products and services (such as market approval and recycling requirements). All these instruments may be central in ensuring markets for new goods and services for specific categories of firms.

Overall, the findings offered by this study appear to be quite relevant from an innovation policy perspective, as they allow the identification of the nature and the best timing of policy intervention and strategic decision in relation to the firm's life course. Indeed, the design of proper and effective policy instruments can be achieved only by identifying why and to what extent different type of companies are excluded from the "innovation arena". More specifically, policy makers might give more relevance to the enlargement of the population of innovative-active firms, by removing or alleviating barriers that prevent firms from engaging in innovation activities; or strengthen the innovation capacity of the existing population of innovative active firms, by removing or attenuating obstacles that obstruct successful completion of innovation projects and adequate returns to innovation investments.

Future research should certainly look beyond the simple distinction that assigns firms to different age groups and explore more deeply the relationship between firm age and firm perception of obstacles to innovation. This might be tackled by employing non-parametric techniques, which would allow us to consider the entire age distribution without assigning any particular functional form to the relationship of interest. Furthermore, to complement the present findings, it would also be interesting to examine the impact the various obstacles to innovation have in hindering the innovation activity (on both the input and output sides) of firms of different ages.

Overall, the growing interest among policy makers and the paucity of contributions on the subjects call for more research into the nature, effects and determinants of

barriers to innovation faced by firms and also for collecting more refined statistical information on these barriers.

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Compliance with ethical standards

Conflict of Interest The author declares that he has no conflict of interest.

Appendix

Table 8 PITEC questionnaire: barriers to innovation

During the three years period ---- how important were the following factors as constraints to your innovation activities or influencing a decision to innovate?

Barrier factors	Barrier items	Factors not exp.	Degree of importance		
			Low	Med	High
Cost factors	Lack of available finance within the firm	☐	☐	☐	☐
	Lack of available finance from other organizations	☐	☐	☐	☐
	Direct innovation costs too high	☐	☐	☐	☐
Knowledge factors	Lack of qualified personnel	☐	☐	☐	☐
	Lack of information on technology	☐	☐	☐	☐
	Lack of information on markets	☐	☐	☐	☐
	Difficulties in finding partners for innovation	☐	☐	☐	☐
Market factors	Market dominated by established enterprises	☐	☐	☐	☐
	Uncertain demand for innovative goods or services				

Table 9 PITEC questionnaire: engagement in innovation activity

During the three-year period, did your enterprise engage in the following innovation activities?	YES	NO
Intramural (in-house) R&D Creative work undertaken within your enterprise on an occasional or regular basis to increase the stock of knowledge and its use to devise new and improved goods, services and processes.	☐	☐
Acquisition of R&D (extramural R&D) Same activities as above, but purchased by your enterprise and performed by other companies (including other enterprises within your group) or by public or private research organisations.	☐	☐
Acquisition of machinery, equipment and software Acquisition of advanced machinery, equipment and computer hardware or software to produce new or significantly improved goods, services, production processes, or delivery methods.	☐	☐
Acquisition of external knowledge Purchase or licensing of patents and non-patented inventions, know-how, and other types of knowledge from other enterprises or organisations.	☐	☐
Training Internal or external training for your personnel specifically for the development and/or introduction of innovations.	☐	☐
All forms of design Expenditure on design functions for the development or implementation of new or improved goods, services and processes. Expenditure on design in the R&D phase of product development should be excluded.	☐	☐
Market introduction of innovations Activities for the market preparation and introduction of new or significantly improved goods and services, including market research and launch advertising.	☐	☐

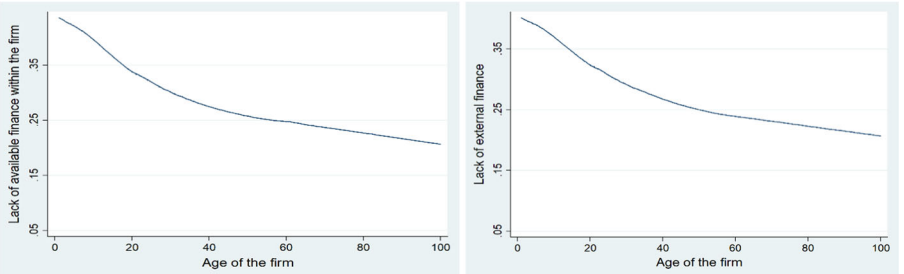

Fig. 1 Local linear smoothing (lowess): relationship between firm age and cost obstacles

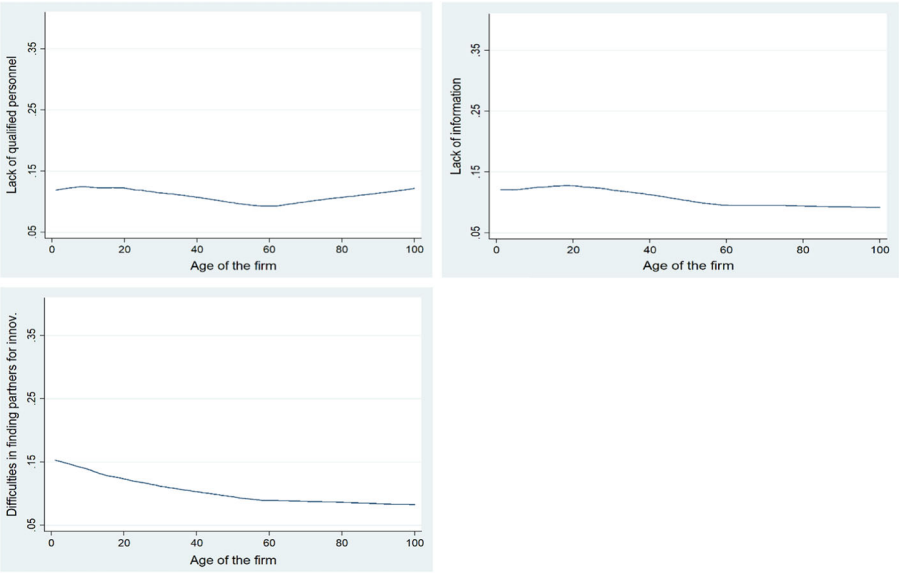

Fig. 2 Local linear smoothing (lowess): relationship between firm age and knowledge obstacles

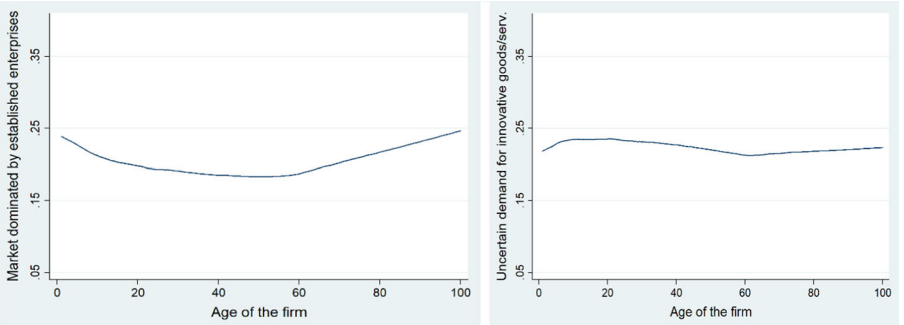

Fig. 3 Local linear smoothing (lowess): relationship between firm age and market obstacles

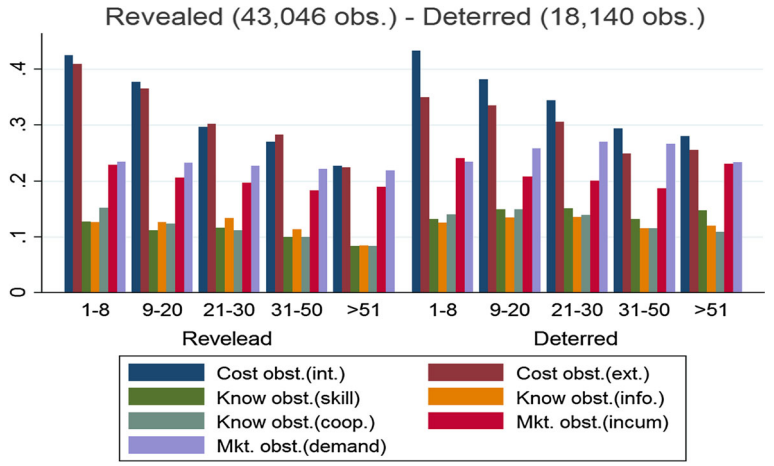

Fig. 4 Average firm's perception of obstacles to innovation by age category (revealed and deterring samples)

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