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WHAT MAKES SOME UNIVERSITY SPIN-OFF FIRMS MORE OPEN IN KNOWLEDGE COLLABORATION THAN OTHER ONES?

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ABSTRACT

Open innovation is well conceptualized and researched for large established firms, but not for small and young ones. What makes small high-technology firms more open in search behaviour and innovation and others more closed, has remained largely unknown. This particularly holds true for university spin-off firms. The paper fills this gap and deals with the extent to which openness is adopted among university spin-off firms. Openness in this paper is measured by two dimensions, capacity and diversity, and an explanation is sought for the variation in these dimensions. For this purpose we develop a set of models including enabling factors and strategic intentions factors, and we control for competition in the business environment and density in the urban environment. Using an exploratory approach in regression analysis, our models of openness diversity (sources of knowledge use) tend to be stronger than the models of openness capacity (size of external knowledge pool). Openness diversity varies with four enabling factors, i.e., science-driven innovation, size of firm, size of founding team and pre-start experience, and with prospector strategy. Location tends also to be important, with a higher level of openness diversity in rural/peripheral areas. Finally, we develop a framework linking openness dimensions and growth of spin-off firms.

Key words: openness, knowledge collaboration, university spin-off firms, enabling factors, strategic intention factors, location, competition.

1. Introduction

The character of innovation by firms has experienced major changes since the 1990s. The source of successful innovation has gone beyond being productive in R&D, improving management practices and delivery of new high quality products and processes to market. Innovation is not solely dependent on discovery of scientific knowledge or formal R&D activities; instead it has become the result of various interactive processes through involving a wide range of parties, like suppliers, customers, competitors, universities, venture capitalists, and government agencies (Chesbrough, 2003, Chesbrough et al., 2006; Leiponen, 2005;

Laursen and Saulter, 2006; Love et al., 2011). In particular, customers are playing an important role in firm learning processes by getting involved much earlier than before, thereby shortening time-to-market and reducing market uncertainty (von Hippel, 2005; Thomke and von Hippel, 2002). The previous trends have been popularized through the concept of open innovation, defined as the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation respectively (Chesbrough, 2003). While, there is an 'outside in' element meaning that innovation in the firm benefits from external inputs, the 'inside out' element refers to the part of innovative activity that finds a customer market through other firms and organizations.

Opening up the innovation process is not just about giving up control and hoping for the best (AWT, 2006; Boudreau and Lakhani, 2009) but it is about implementing mechanisms to govern, shape, maintain and, if necessary, constrain external innovators. Thus, successful firms are those that invest in effective knowledge relationships with suppliers, sub-contractors, knowledge-intensive firms, experts/advisors, universities and research institutes (Hughes et al., 2007; Mansury and Love, 2008; Belussi et al., 2010), using a strategic selection and selective maintenance of such knowledge relationships. In this vein, we conceive openness of a firm as its actually established relationships with external actors (Dahlander and Gann, 2010).

There are many definitions of university spin-offs, each dependent on the specific context (e.g., Bathelt et al., 2010; Djokovic and Souitaris, 2008). University spin-off firms are defined in this paper as a particular type of young high technology firms, created for the purpose of commercially exploiting knowledge, technology or research results developed within a university (Pirnay et al., 2003). This situation means that the entrepreneur is often a graduate, a university staff member, or an external entrepreneur exploiting university knowledge. The presence of the first actor comes often with a lack of resources, except for technical knowledge.

University spin-off firms, however, are to a certain extent heterogeneous, starting with different capabilities and resources - as evidenced in different founding teams (Druilhe and Garnsey, 2004; Heirman and Clarysse, 2004; Colombo and Grilli, 2010). They also develop different strategies in grasping opportunities, causing different needs for openness in knowledge collaboration (Andersson, 2006; Mohr et al., 2010; van Geenhuizen and Soetanto, 2009). This heterogeneity of spin-off firms connects with theoretical ideas of Teece (2007) through which different openness levels of firms may be understood given a set of enabling factors like firm size, firm age, and quality of founding team, and a set of firms' strategic

intention factors like level of innovativeness and the ambition to grow. Moreover, from an organizational point of view, past experiences of founding teams may limit the focus in building external networks, as a result of path-dependency and lock-in effects (Arthur, 1993; Cohen and Levinthal, 1990; Nelson and Winter, 1982).

In addition, but from another perspective, spin-offs may differ in openness according to the urban location, with more openness of firms in small cities in rural areas – compensating for local knowledge deficiency - compared with cities in large metropolitan areas (Isakson and Onsager, 2010; de Jong and Freel, 2010). Overall, openness in innovation practices is not adopted by all spin-off firms to the same extent and also not in the same way. Openness is increasingly studied as an important influence on firm innovation and broader performance (e.g., Deshpande and Farley, 2004; Laursen and Salter, 2004, 2006; Fu, 2012), but causes of differentiation have seldom been revealed.

There are various knowledge gaps to which this paper responds. First, there is a lack of understanding on what openness and open innovation constitute in terms of main components and dimensions, and what factors cause differences in openness between firms. Secondly, as previously indicated, small firms have almost been neglected in open innovation research, among them the class of university spin-off firms, with notable exceptions like van de Vrande et al. (2009), Gassman et al., (2010) and Hayter (2010). Thirdly, there is a lack of insights derived from research that adopts quantitative approaches. In line with these knowledge gaps, the paper addresses the following questions: 1) What is the pattern of openness among university spin-off firms? 2) Which factors contribute to differences in openness? And 3) what is the contribution of openness to firm growth?

The paper draws on a sample of 105 university spin-off firms while using a quantitative approach, and is structured as follows. Section 2 discusses theory and the model design. Methodological aspects of the study are addressed in Section 3, which also includes a description of the sample and a descriptive analysis of openness among spin-off firms in the sample. This is followed by multiple regression analysis in an attempt to clarify the differentiation in openness (section 4). In section 5, the contribution of openness to firm growth is discussed. The paper closes with an evaluation of the results and a brief indication of policy implications.

2. Enabling factors and strategic intention factors

The literature on university spin-offs' growth has mainly focused on the performance of these firms and factors differentiating in this performance. For example, from a development perspective, growth tends to be related to capabilities to overcome or prevent critical junctures or obstacles (Vohora et al., 2004; van Geenhuizen and Soetanto, 2009). However, almost none of the studies of spin-off firms' growth takes explicitly an open attitude or openness into account. We therefore use the wider entrepreneurship literature on small high-technology firms and high-technology ventures while adopting the knowledge-based view on spin-off firms (Grant, 1996). We 'merge' thinking of two related bodies of theory, which are the resource-based view and dynamic capabilities (Barney and Clark, 2007; Wernerfelt, 1995; Teece, 2007) and organizational learning (Nelson and Winter, 1982; Arthur, 1993; Cohen and Levinthal, 1990; March, 1991; Winter, 2003; McKelvie and Davidsson, 2009) in developing theoretical arguments about differentiation in openness of spin-off firms.

We approach differentiation in openness by using enabling factors and strategic intention factors. The first ones include firm age and size, drivers of innovation, size of founding team and prestart experience, whereas we divide the second ones into strategies and ambitions. We develop theoretical ideas on how two dimensions of openness may be different between spin-off firms: (1) size of the outside knowledge pool used (indicated in the paper as *openness capacity*), and (2) diversity in the sources of knowledge use (indicated as *openness diversity*) (Leiponen and Helfat, 2005; Laursen and Salter, 2006; Chiang and Hung, 2010).

Firm age and size

Age and size of spin-off firms and the relation with growth and innovation have received strong attention in the literature (Rothaermel and Deeds, 2004; Rothaermel et al., 2007). It seems that if resources and capacities increase with age and size, openness tends to increase proportionally. However, within each growth process, at one point in time, increases slow down, and are followed by a decreasing growth. This pattern is well known in broader economic work as decreasing returns, eventually lock-in (Arthur, 1994; Grabher, 1993). From an evolutionary perspective, the phenomenon can be explained as follows: accumulated capabilities of firms may after some time start to limit the scope of search and the capacity to comprehend and applying new knowledge (Cohen and Levinthal, 1990; Nelson and Winter, 1982). Thus, spin-offs, after some years of fast increase of openness capacity, may start to suffer from not only capacity shortages, also named the 'attention allocation problem' (Simon, 1947; Ocasio, 1997), but also shortage in managerial competence. Moreover, locked-in routines grown in past years cause a larger effort to understand norms, habits and routines

of searching and to rely on additional external knowledge channels (Laursen and Salter, 2006; Dahlander and Gann, 2010).

Similar mechanisms seem at work in growth of openness diversity, showing first a quick increase of diversity of partners in networks followed by a flattening and eventually a decrease in diversity. Thus, spin-off firms after a certain point may become 'blind' for additional partner diversity and start to reduce their efforts in extending the network accordingly.

Drivers of innovation

With regard to learning mode and sources of innovation, spin-off firms can be divided into two categories, science-based and non-science-based firms. This goes back to differences between the main driver of innovation, i.e. science or market (Tidd et al. 2005; Asheim et al., 2007). Science-based firms aim to create inventions based on research drawing on laws of nature and these inventions are often more radical in nature, like in biotechnology, material science and optics, while non-science-based counterparts are involved in engineering- or problem-based types of learning.

Radical innovators are likely to draw more deeply from external sources of innovation than firms that are not radical innovators (Laursen and Salter, 2006). Moreover, science-based spin-off firms, which are usually involved in a more complex, high risk and rapid-changing environment, need more information and knowledge from financial institutes, public authority, and large firms (Amit and Shoemaker, 1993; Mohr et al., 2010). Therefore, it seems that the science-based spin-offs create a 'larger' openness, which enables them to respond immediately to outcomes of development among competitors, both in technology and market.

Competition level

Various studies prove that search strategies by innovative firms are strongly influenced by the richness of technological opportunities in the environment and by the search activities of other firms (Nelson and Winter, 1982; Levinthal and March, 1993). Thus, in industries with high levels of technological opportunities and large investment in competitive search by firms, there is often a need to search more widely and deeply in order to get access to critical knowledge sources (Laursen and Salter, 2006).

Size of founding team

Founding teams represent different combinations of capabilities of spin-off firms at start (Colombo and Grilli, 2005, 2010). Usually founding teams' size ranges from two to five persons. Views on the influence of founding team size on performance of young ventures are divided, some literatures say that with a large size there is a larger capability to build the initial external networks both concerning openness capacity and openness diversity (Davidsson et al., 2005; Cooper et al., 1994). However, in the broader literature on team management, larger founding teams are assumed to increase the chance of 'social loafing', thereby reducing the efforts in building networks for gaining knowledge and information (McShane and Travaglione, 2007; Robbins and Judge, 2011). In general, 'social loafing' occurs when people exert less effort and perform at lower levels if working in a group compared to working solely.

Pre-start experience in founding team (breadth and depth)

Pre-start experience in the founding team has received a lot of attention in research on new ventures performance (van Praag, 2003; Lee et al., 2010; Colombo and Grilli, 2005, 2010). The focus in this research is often on type of experience, namely, start-up experience, managerial, organizational and R&D experience, and similarity of the experience with the sector of the new venture. However, there is not much empirical research on the influence of pre-start experience on building networks, but we guess that if there is a positive influence on firm performance, openness in networks is part of it.

In the current study, we distinguish between the breadth of experience indicated by diverse areas, like management and R&D, and the depth of the experience, indicated by number of years of experience in the same sector. One of the studies in this area (Beckman et al., 2007) confirms that founding teams with diverse functional backgrounds, breadth of experience in our study, are capable to reach entrepreneurial milestones quicker compared to non/less diverse teams. Moreover, a broad experience of founding teams makes a firm more attractive to external stakeholders and to investors. These arguments make us assume that with a broad pre-start experience in the founding team, spin-off firms will me more open.

In addition, it is argued in the literature that new ventures with experienced managers are better able to identify opportunities and threats because of their greater familiarity with the specificities of their respective industries. More importantly, it is especially evident in high-technology new ventures that prior industry experience tends to be positively associated with new venture performance (McGee and Dowling, 1994). Similarly, Cooper et al. (1994) suggest that availability of know-how specific to the industry or line of business may bring

relevant knowledge bases, experiences, and relationships that significantly reduce the liability of newness. Colombo and Grilli (2005) conclude that influence on performance is most positive if sector-specific knowledge is part of the experience. Among the advantages is also a larger openness, based on the ability to connect relatively easy with the industry sector and main players. Conversely, other research demonstrates that prior start-up experience may also have a negative relationship with firm outcomes (Beckman et al., 2007). A deep prior experience may cause 'lock-in' due to strong self-confidence and strong self-reliance (Cohen and Levinthal, 1990; Nelson and Winter, 1982). Aspelund et al. (2005) report a positive impact of experience on firm survival but nevertheless give a warning for path dependency. Similarly, Dencker et al. (2009) prove that survival benefits created by learning activities may be facilitated or constrained by founders' pre-entry knowledge and experience. Path dependency and lock-in connected with pre-entry experience may result in a more closed way of innovation and knowledge gathering. Overall, we may conclude that there are different opinions about impacts of depth in pre-start experience on openness of spin-off firms.

Strategy and ambitions to grow

High-technology ventures may adopt a so-called prospector strategy which indicates a desire for rapid new product development, seeking out new opportunities and taking risks (Miles et al., 1978). A prospector strategy often goes along with being a market pioneer, and the first with innovative new products in different markets. As high uncertainty surrounds the development of new products and new technology applications, prospectors have to maintain flexibility, adaptability, and speed to adopt a decentralized organizational structure (Mohr et al., 2010; Slater et al., 2011). To identify new areas of opportunity and threats, prospectors must be able to scan a wide range of external conditions, trends, and events, thus, they need a heavy investment in individuals and groups who scan the environment for potential opportunities, including those in external networks (Miles et al., 1978). Moreover, prospector innovators need to be flexible and open toward external sources (Slater et al., 2010). Therefore, employing a prospector strategy seems to require a relatively large openness, both in capacity and diversity openness compared to other spin-off firms.

To our knowledge, studies on the relationship between firm ambition level and openness are very rare. However, the concept of ambitions doesn't stand alone, but is related to other concepts/variables already addressed above. For example, firms with a higher ambition level – like to become large and active in global markets - may be motivated to pursue a prospector strategy. A strong desire for global expansion has implications for cross-

border collaborations, requiring a more open strategy. An 'outgoing' spirit may also lead to the establishment of a large number of network relationships, which means a larger capacity.

Summary

We also explore location as a factor of influence and adopt the expectation that firms in the city of Trondheim are more open than the ones in the city of Delft. The underlying argument is that firms' openness in Trondheim compensates for deficiencies in the local environment (such as the presence of launching customers and particular suppliers) by connecting with other regions and abroad (Feldman 1994, 1999; de Jong and Freel, 2010). We summarize the above discussion in Table 1.

Table 1 Summary of factors and expected influence on openness

Factor	**Direction of relationship with openness**
Age and size	Curvilinear (starting as a positive relation but changing into a negative relation)
Drivers of innovation (science-based)	Positive
Size of founding team	Not clear/no consensus
Broad pre-start experience founding team	Positive
Deep pre-start experience founding team	Not clear/no consensus
Prospector strategy	Positive
Ambition level	Positive
Urban environment (rural/periphery)	Positive
Competitive environment	Positive

Note that not all above factors are included in our final models. This follows from solving multicollinearity issues, and from using a stepwise regression analysis, starting with all factors and reducing them one by one to have the least decreasing influence on R^2 and statistical significance of the model.

3. Methodological aspects

3.1 Sample

A sample of 105 spin-off firms, from two technical universities, Delft University of Technology and National Technical University of Norway in Trondheim, is studied (Note 1). The Netherlands and Norway share a similar, rather risk-avoiding culture in entrepreneurship and are both qualified as innovation followers (Pro-Inno Europe, 2010), while both countries

are facing relatively small domestic markets causing similar needs for openness in export among firms. This means that while comparing cities in both countries, the pattern is not distorted by different national influences. Delft is a small town, with 97.000 inhabitants, and it is a part of the southern Randstad metropolitan area that stretches from Leiden in the north via The Hague, Rotterdam to Dordrecht and neighbouring towns in the southeast (Province of South-Holland).

The major industry in this area is commercial and service industry with a notable concentration of port activity, including manufacturing, in the Rotterdam-Rijnmond area (Statistics Netherlands, 2010). The major industries in Trøndelag area, where Trondheim is, encompass mining, agriculture including farmed fish and processed wood, Note that oil and gas production is the fastest growing sector (Statistics Norway, 2010). With regard to size of the economy, the South Holland economy is eight times bigger than the economy of Trøndelag. Trondheim is a single city (173.000 inhabitants) at a large distance from large cities, for example, the distance from Trondheim to Oslo and Bergen is approximately 400 km and to Stockholm (Sweden) approximately 600 km. Although Trondheim, unlike Delft, is in a peripheral and rural area, it has an important function as a knowledge city, and it is the third largest city in Norway.

3.2 Measurement

We measured openness in two dimensions: capacity and diversity (see Table 2, see also Annex 1). Openness capacity, as the 'size' of the external knowledge pool, was originally conceptualized as a two-dimensional variable composed of breadth and depth. Breadth, number of different types of knowledge received from partners, and depth, tie strength between the firm and its partners, virtually constitute a knowledge pool that the firm can access. Diversity, on the other hand, is about the heterogeneity of partners' social backgrounds, including spatial orientation of the firm. An external spatial orientation can be beneficial for bringing in new ideas and knowledge, thus strengthening the diversity of external knowledge (Soetanto, 2009). We measured the dependent variables and independent variables as presented in Table 2.

Table 2 Variables and descriptive statistics

Variables	Measurement	Descriptive statistics
DEPENDENT		

VARIABLES		
Openness Capacity	Continuous variable: indicates the size of the external knowledge pool (two dimensional 'pool' constructed of 'breadth' and 'depth')	Average: 6.28 standard deviation: 3.80 min-max: 1.08-20.35
Openness Diversity	Continuous variable: indicates the diversity of the external knowledge pool, and includes both heterogeneity of actors and spatial orientation	Average: 0.35 standard deviation: 0.19 min-max: 0-0.88
INDEPENDENT VARIABLES		
Urban environment (control variable)	Variable in two categories of cities, as a dummy (Trondheim=1)	Delft: 58% Trondheim: 42%
Business environment - competitive level (control variable)	Variable indicating the competitive level of spin-offs' environment (many competitors=1, few competitors=0)	Many competitors: 56% Few competitors: 44%
Enabling factors		
Drivers of innovation	Variable in two categories: science-based versus non-science based, as a dummy	Science-based: 27% Non-science based: 73%
Firm age	Continuous variable: number of years since firm foundation to 2007	Average: 4.93 standard deviation: 3.06 min-max: 0-10
Firm size	Continuous variable: number of full time equivalent in 2007	Average: 7.19 standard deviation: 6.9 min-max: 0.5-51
Size of founding team	Number of team members at foundation	Average: 2.28 standard deviation: 1.19 min-max: 1-5
Pre-start experience breadth	Variable in four categories based on founders' experience in research/ management, and other areas	Average: 1.14 standard deviation: 0.9 min-max range: 0-3
Pre-start experience depth	Continuous variable: sum of years of all founders' pre-start working experience in similar industries	Average: 7.30 standard deviation: 13.4 min-max range: 0-73
Strategic intention factors		
Overall ambition level	Variable in three categories: large firm with international orientation; small firm with international orientation; small firm with local orientation, and others.	Large firm with int. orientation: 36%; small firm with int. orientation: 50.5%; small firm with local orientation and others: 13.5%
R&D expenditure	Continuous variable: percentage of turnover (income) spent on R&D over the last three years	Average: 39.81 standard deviation: 23.1 min-max range: 0-100
Newness in innovation strategy	Variable in three categories based on type of innovation (breakthrough and/or new to the sector)	High level: 46% Medium level: 29% Low level: 25%
Patenting strategy	Variable in two categories: product/process patented (1) versus non patented (0), as a dummy	Patented: 44% Non patented: 56%
Stage in new product/ process development	Variable in two categories: development/pilot/testing versus	Development/pilot/testing: 37% Introduced to market, incl.

	exploitation (introduced to market, incl. consultancy)	consultancy: 63%

N (firms) = 105

3.3 Descriptive analysis

With regard to openness capacity, the spin-off firms in our sample use more than half of the available information/knowledge types on average, given a choice of eleven different knowledge/information types. Moreover, most firms prefer to gain information/knowledge about new market/customers, competitors, industrial trends and managerial advice, a picture that is partly confirmed in other studies (Laursen and Salter, 2006; Mansury and Love, 2008; Love et al., 2011). Overall, openness capacity shows a mean of 6.3 with a standard deviation of 3.8 and a range of 1.1 to 20.4. Concerning openness diversity, the firms in the database show a rather low average as witnessed by 0.35 with a standard deviation of 0.2 and a range between zero and 0.88 (in the following parts of the study, openness capacity and diversity are standardized for the sake of convenience).

The description of independent variables starts with a discussion of the *control variables*, the urban environment and the business environment. Spin-off firms representing large metropolitan areas, Delft, have a share of 58% and those representing cities in rural and peripheral regions, Trondheim, have a share of 42% in the sample. Fifty-six present of the firms are active in a highly competitive environment and the rest, 44%, are in environments with a few competitors. With regard to *enabling factors*, spin-off firms in sectors with science-based learning are a minority (27%) while most of the firms (73%) are in other sectors, meaning that their learning and innovation are driven by problems or market demand in engineering/design sectors. Most spin-off firms in this category are software firms. On average, spin-off firms in the sample are almost five years old, with a standard deviation of three years. They employ on average seven full time equivalents (fte) at the time of survey, but the standard deviation indicates quite some differences within the sample. The spin-off firms started on average with two team members at the foundation. Regarding pre-start experience in the founding team in terms of breadth, the spin-off firms have on average one type of experience, including research, management or other types of experiences. The share of the sample facing one type of experience is 62%. In addition, spin-off firms' founders with experience have on average seven years of relevant experience in the same sector/industry.

With regard to *strategic intention factors*, the spin-off firms in our sample have a moderate overall ambition to grow, witnessed by 36% of firms aiming to become a large firm with international orientation and by around half (51%) aiming to become a small firm with an international orientation. The firms spend on average 40% of their turnover/income on R&D activity, but a relatively large standard deviation indicates quite some differentiation. With regard to the newness of innovations, 46% of the spin-off firms are dealing with products/processes in the highest category, namely, a breakthrough and new to the sector, while 25% are involved in low level newness, namely, an already accepted product, process or service with minor improvements. This connects with the patenting strategy, with 44% of the spin-off firms in the sample employing such a strategy. In next step of the analysis, given a high correlation, R&D expenditure, newness in innovation strategy and patenting strategy, are 'bundled' in a new variable, i.e., 'prospector strategy' (see Annex 2).

4. Towards Understanding of Openness

We explored models for two different dimensions of openness, namely, capacity and diversity. The type of multiple regression analysis used was the backward stepwise method. In this method, first, the full regression model was run including all the independent variables which are highly correlated with openness. Next, the variables were removed one by one in such a way that the model power, R^2, and statistical significance of the model decreased to the smallest extent.

A high correlation between firm size and firm age and their importance in this analysis urged us to include these two variables separately in two models. Therefore, for each of the openness dimensions, we explored at two models, model 1 including size and model 2 including age (Table 3). With regard to the diagnostic tests, generally all tests were satisfied in meeting the assumptions: there were no severe concerns for outliers, the residuals were normally distributed and homogeneous, no multicollinearity problems existed, and the tests for model specification errors produced satisfactory results (Annex 3). In addition, endogeneity of the model was addressed (Annex 4). In terms of power by R^2, the model on openness diversity, model 1, is the strongest (R^2=0.52). Thus, the set of selected variables in this model produced the highest level of explanation of openness. An 'isolated' urban environment, the enabling factors science-based innovation, spin-off size, size of the

founding team, and breadth of experience in this team, as well as a prospector strategy are among significant variables in this model. With regard to the capacity dimension of openness, R^2 reaches a value of 0.21.

Overall, the results of the backward stepwise approach show that enabling factors tend to have a stronger influence on openness capacity and diversity than strategic intention factors. Particularly, openness capacity is just influenced by enabling factors. We may understand this as follows: enabling factors are concerned with what the spin-offs may achieve due to their internal resources and capabilities and innovation driver, and this directly affects the networks and knowledge pools they build and maintain. However, this may work into two different directions, smallness within the firm or founding team may make it necessary to extend externally, but also: smallness within the firm or founding team may make it impossible to do so due to short in resources and capabilities. This situation could be an explanation for differences in sign of the bête-coefficients, like for size of firm and size of founding team with regard to capacity model 1, but also with regard to diversity model 1. The same may hold true for age when comparing between capacity model 2 and diversity model 2. Another explanation is that there may be underlying non-linear relations (e.g. curvilinear) between openness and some variables (e.g. firm age and firm size).

We now discuss the capacity and diversity models in more detail. Our control variables produce significant results and conform to other studies: spin-off firms in Trondheim tend to be more open with regard to diversity (de Jong and Freel, 2011) and a high competition level in the business environment tends to make firms to be more open in searching for knowledge (Laursen and Salter 2005). Among *enabling factors*, firm size is significant in both models while it tends to produce a negative impact on openness capacity and a positive impact on openness diversity. The age of spin-offs tends to positively influence openness diversity, not capacity. Size of the founding team is found to be significant in both models of capacity and diversity but with opposite signs. Larger founding teams tend to contribute to a higher level of the capacity dimension but to a lower level of the diversity dimension.

We found that firm size has a curvilinear relationship with openness, on both dimensions (Figure 1) but this relationship indicates a different pattern for capacity, a trend of decreasing returns, compared to diversity, a trend of increasing returns. Also, firm age shows a curvilinear relationship with both dimensions of openness. This pattern points to influence of path dependency and lock-in: an initial growth of openness is followed by a slow-down and a decrease of openness.

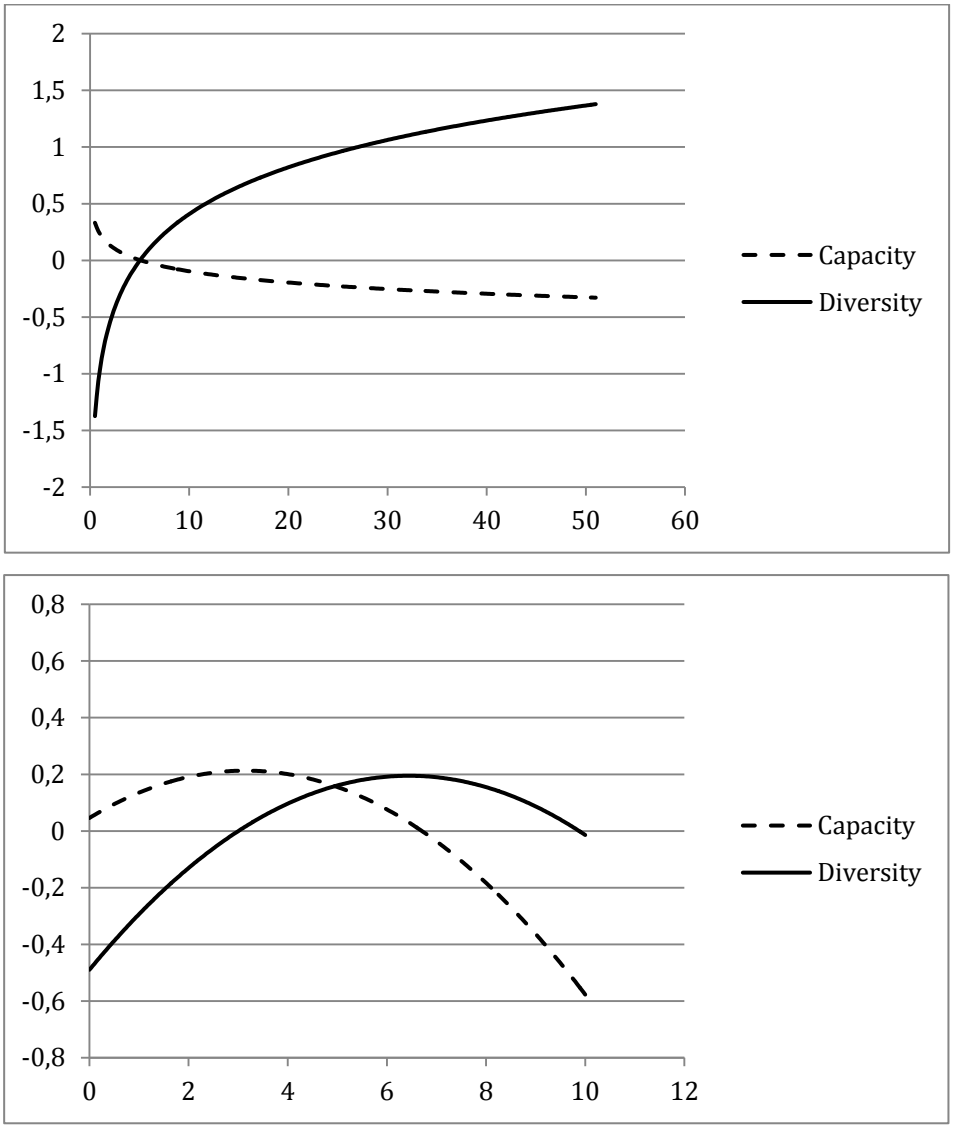

Figure 1 Curvilinear relationships between firm size and age and openness: top – firm size versus openness, bottom – firm age versus openness.

With regard to the drivers of innovation and learning, science-based firms tend to face a larger openness diversity. In addition, diversity tends to be strengthened by the breadth of pre-start experience, while the depth of pre-start experience tends to have a negative influence on capacity. Regarding the *strategic intention factors*, the overall ambition level tends to play

a positive and significant role in openness diversity (model 2). Moreover, employing a 'prospector strategy' was found to have a positive and significant influence in both diversity models. The last result may be explained as follows: spin-offs at high level of newness, prospectors, involved in protected knowledge feel more freedom to connect with different parties and to exchange knowledge with them. In addition, patented knowledge gives a firm a higher credibility and makes a firm a more attractive partner (Taheri and van Geenhuizen, 2011).

Table 3 Stepwise regression analysis of openness

	Openness Capacity		**Openness Diversity**	
	Model 1	Model 2	Model 1	Model 2
	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)
Control variables				
Urban environment (Trondheim=1)	-	-	0.43 (0.16)***	0.38 (0.19)**
Business environment-Competitive level	0.39 (0.16)**	0.47 (0.18)***	-	-
Enabling factors				
Drivers of innovation (science-based = 1)	-	0.29 (0.20)	0.38 (0.19)**	-
Firm age	-	-0.22 (0.12)*	-	0.39 (0.12)***
Firm size	-0.29 (0.10)***	-	0.89 (0.10)***	-
Size of founding team	0.73 (0.24)***	0.51 (0.25)**	-0.36 (0.21)*	-
Pre-start experience breadth	-	-	0.20 (0.08)**	0.14 (0.10)
Pre-start experience depth	-0.04 (0.02)**	-0.04 (0.02)**	-	-
Strategic intention factors				
Overall ambition level	0.08 (0.08)	-	-	0.23 (0.09)**
Prospector strategy	-	-	0.20 (0.09)**	0.20 (0.12)*
N^2	102	102	102	101
F	5.03***	4.86***	17.07***	5.74***
R^2	0.21	0.20	0.52	0.23
Root MSE	0.81	0.81	0.72	0.86

* p<0.1; ** p<0.05; *** p<0.01

In a final step, we also explored various interaction effects (Table 4). Since the variables that are assumed to have interactions (the two pairs: *firm size* and *location, overall ambition level* and *firm age*) are only fully present in the two models of diversity, interaction effects are explored only in this dimension of openness. The results are highly consistent with our expectations: as firms grow older, they 'keep up' their ambition level in order to maintain a strong desire to reach out for diverse partners; and, spin-offs residing in rural and peripheral area like Trondheim are forced to pursue an internal resource orientation, which means a larger firm size, to compensate their lack of external supports. The moderator *firm size* and

location slightly improves the R^2 of the model (model 1) by 0.03, while *overall ambition level* and *firm age* have a stronger effect of 0.08 extra on R^2 in model 2.

Table 4 Interaction effects

	Openness Diversity	
	1	2
	β (s.e.)	β (s.e.)
Control variables		
Urban environment (Trondheim=1)	0.46 (0.15)***	0.40 (0.18)**
Business environment-competitive level	-	-
Enabling factors		
Drivers of innovation (science-based = 1)	0.38 (0.18)**	-
Firm age	-	0.46 (0.12)***
Firm size	0.93 (0.10)***	-
Size of founding team	-0.44 (0.21)**	-
Pre-start experience breadth	0.21 (0.08)**	0.14 (0.10)
Pre-start experience depth	-	-
Strategic intention factors		
Overall ambition level	-	0.28 (0.09)***
Prospector strategy	0.21 (0.09)**	0.16 (0.11)*
Interacting effects		
Location x Firm size	0.51 (0.19)***	
Firm age x Overall ambition level		0.40 (0.12)***
N	102	101
F	16.73***	7.09***
R^2	0.55	0.31
ΔR^2	0.03***	0.08***
Root MSE	0.69	0.82

* p<0.1; ** p<0.05; *** p<0.01

5. From Openness to Growth

As proposed by Deshpande and Farley (2004), relatively open, externally oriented organizational cultures are related to better performance, while relatively closed, internally oriented organizational cultures are related to poorer performance. However, to what extent can openness lead to a better performance, and how can this performance produce benefits to growth of small firms like university spin-offs still remain a question. Capturing two dimensions of openness as we discussed previously, and using longitudinal data on job growth and turnover growth of spin-off firms between 2006 and 2010, it was possible to explore the relationship between openness and growth.

There are different forms of growth, among which the most common ones are employee (job) growth, turnover (sales) growth and asset growth. Limited to our dataset, only (absolute) job growth and turnover growth were taken into account. Job growth was measured by the difference between the number of employees in 2010 and 2006 (fte), whereas turnover growth was measured as the difference between two ordinal variables in 4 categories: no turnover, <100.000, 100.000-300.000, and >300.000 in 2010 and 2006. Because of the intrinsic difference between organic and non-organic growth (Davidsson et al., 2005, 2006), an 'organic' sample was selected out of the 105 spin-off firms, excluding the failed and integrated ones, with a sample size of 92. The frequency distribution of these two types of growth is summarized in Figure 2.

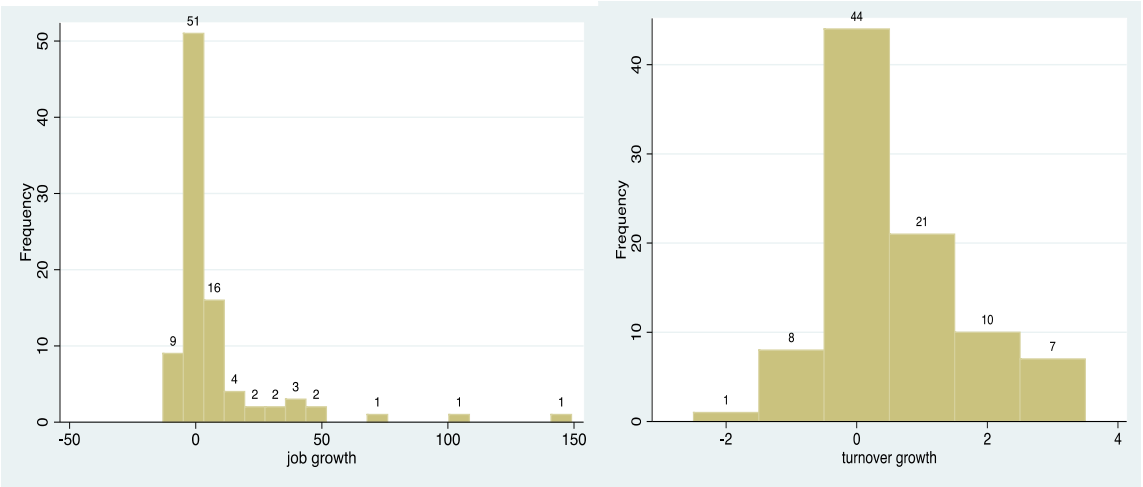

Figure 2 Frequency distribution of job growth (left) and turnover growth (right)

In order to link openness with the above-described growth, we developed a framework of openness as presented in Figure 3, using standardized values of openness capacity and openness diversity, in which four situations can be distinguished. The attitude among firms, quarter 3, refers to a relatively closed knowledge collaboration model, indicated by low values of both capacity and diversity. In addition, firms with more focused and less diverse knowledge partners benefiting from high capacity knowledge pools, quarter 1, might strongly rely on some specific types of knowledge and strongly depend on certain sources of knowledge. Among these firms we observed the highest turnover growth rates compared to firms in others quarters. Conversely, among firms with a diverse range of partners, with weak ties in getting access to knowledge, quarter 4, we observed the highest rates of job growth among the four quarters (an average job growth of 15.8). In fact, these temporary and transient ties can provide information and resources beyond what is available in a closed

social circle, thus contributing to the innovation practice (Granovetter, 1983). Finally, the firms with a highly open attitude in knowledge collaboration, quarter 2, invest a lot in both diversity and capacity, allowing themselves to react fast to the turbulent environment and act as a prospector in launching new products or services. However, they are also facing relatively large risks which tends to hamper their growth.

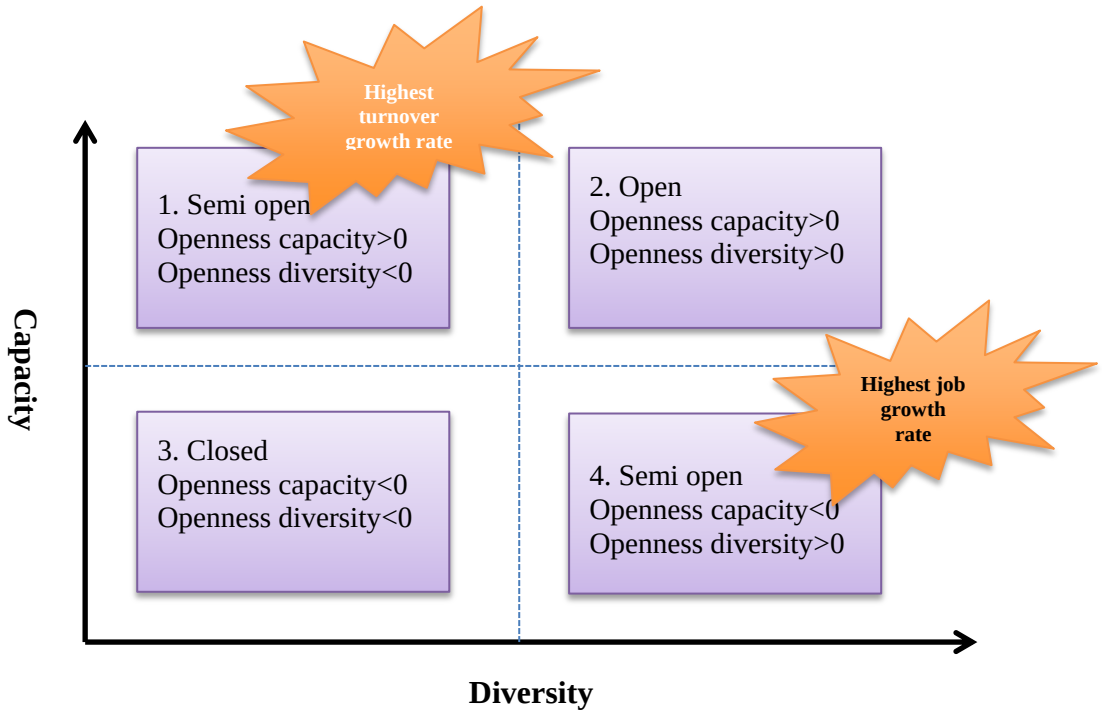

Figure 3 A simplified model of openness and spin-off growth

Considering the framework in Figure 3, and taking the heterogeneity of spin-offs in our sample into account, we may conclude that a strategy blindly targeting openness is neither wise nor beneficial for growth. Thus, the strategy on openness should be based on a solid investigation of spin-offs capabilities/resources, their environment and context, and the overall match of openness strategy with the vision and ambitions of spin-off firms.

6. Discussion and conclusion

We began this paper with the observation that in spite of the growing literature on openness, there is a lack of clarity and shortage of research on openness among small technology-based firms, particularly university spin-offs. We studied openness among these firms along two dimensions of openness in knowledge/information flow, namely, capacity and diversity.

Therefore, this paper contributed to a better understanding of open innovation and openness among small technology-based firms. In our attempts to understand the variation in openness, we explored two models including enabling factors and strategic intention factors, as well as the urban environment and competition in the business environment. The estimation results of a backward stepwise regression approach showed that *enabling factors*, like age, firm size, size of founding team and pre-start experience in this team, tend to have a stronger influence on openness capacity and diversity than *strategic intention factors*. Particularly, the openness capacity was just influenced by enabling factors. However, the direction of the influence was sometimes different, indicating two sides of smallness and a young age: a pressing need for openness and open innovation but at the same time limited resources and capabilities to do so. Regarding the *strategic intention factors*, the overall ambition level tended to play a positive and significant role in openness diversity, as does an 'aggressive' innovation strategy (by prospector firms). Further, *urban environment* turned out to matter in openness, so did *level of competition* in the business environment.

With respect to policy making and management, our results showed clear differences in openness between spin-off firms, mainly due to enabling factors, but also due to the two strategic intention factors, overall ambition level and prospector strategy. If managers of incubators want to support in increasing openness of spin-off firms, they can only impact upon factors that can be easily influenced. One is size of the founding team: our contradictory results point to a need for a balance between a too small size and a too large size. In addition, support should be given with care because path dependency and lock-in effects may arise. The other factors are overall ambition and prospector strategy. Promoting the last strategy may increase openness. Potential measures to support this are, for example, simplifying patent procedures and reducing patenting costs for spin-off firms.

There were also some limitations in this study. First, due to the relatively small sample size, the openness model was measured by a limited number of indicators, thereby excluding other features of openness. Second, due to data limitations we could just measure the inflow of knowledge to the firm, meaning that outflows and outsourcing were excluded from the analysis. Thus, future research could include other inflow modes, such as licenses and formal agreements on collaboration, but also outflow modes to better understand the openness and open innovation concepts. Also, by investigating the influence of openness on firm performance or growth, we could derive a better picture of whether and to what extent openness is favorable. The relationship with firm performance will be a next step in our research.

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Note 1. Data collection
Using a meta-analysis of growth of university-related incubators (van Geenhuizen and Soetanto, 2009), the universities in Delft and Trondheim were identified as two viable cases. In a next step, we delineated the population of spin-offs from TU Delft and NTNU on the basis of the following criteria. First, the firms needed to satisfy the condition of commercializing knowledge created at a university and were to be found in Delft/Trondheim or their surrounding regions. Further, the firms had to satisfy the condition of "survived in 2006", and being no older than 10 years. We approached all firms in this population (150) and obtained an overall response rate of 70% (105 firms). Data were collected using a semi-structured questionnaire in personal face-to-face interviews with entrepreneurs, carried out by the two authors in the period 2005 to mid-2006. Note that excluding non-survivors is a common source of bias in the results of studies like the current one, however, it appears that mortality rates among university spin-off firms are relatively low in the European Union. Mustar et al. (2007) suggest that 75% have survived after six years. Local experts in Delft even suggest 80 to 90% (personal communication).

Annex 1
Openness capacity
Openness capacity was defined as the amount of knowledge that a firm was linked to and possibly could benefit from, which was composed of both "breadth" and "depth" of external knowledge sources (Laursen and Salter, 2006). External search breadth is defined as "the number of different search channels that a firm draws upon in its innovative activities", while the external search depth is "the extent to which firms draw intensively from different search channels or sources of innovative ideas". The concept of "breadth" and "depth" adjusted in this study as two sub-dimensions to constitute the "capacity" of external knowledge pool. Therefore, the value of openness capacity can be given as

$$Cap = \sum_{i=1}^{n}(B_i \times D_i) \quad (1)$$

where *n* is the number of types of external information and knowledge. We expect that the larger the external knowledge capacity, the more "open" a USO is. The breadth B_i is simply the counted number of partners within a knowledge content, while the depth D_i requires a further calculation.

As noted before, there are B_i partners within the knowledge content *i*, each has a "depth" as $d_j\ (j = 1 \dots N)$, which is a composite variable derived from variables on frequency of interaction (*r*), duration of relationship (*u*), and entrepreneurs' assessment of closeness of the relationship (*c*, *M*-rank categorical variable) (Burt, 1992) as mentioned before:

$$\begin{cases} r_j = r \times l \\ u_j = \ln(u+1) \\ c_j = \frac{c}{M} \end{cases} \quad (2)$$

where r_j, u_j and c_j are the frequency of interaction, duration of relationship and entrepreneurs' assessment of closeness of the relationship for the partner *j*. $r \times l$ can be seen as "frequency-distance product", which intends to eliminate the distance as a comtamination of freqency of interaction. Note that before the operation of multiplication, both r and l are tranformed to logarthrim format, in order to "strengthen" the effect of the former one since overall it has a small value, and "weaken" the effect of the latter one, assuming that the influence is more gentle when exceed a certain value. These variables will be further normalized as follows:

$$\begin{cases} r_j^* = r_j/(\max(r_j)) \\ u_j^* = u_j/(\max(u_j)) \\ c_j^* = c_j \end{cases} \quad (3)$$

where r_j^*, u_j^* and c_j^* are the normalized variables of r_j, u_j and c_j (for each variable, min: 0; max: 1). Here the min-max normalization is used to scale the value between 0 and 1, and make the data more interpretable (note that the minimum value is 0 so it is omitted).

Unlike in previous research suggesting an equal contribution of the three indicators to the tie strength, another weighting method is proposed here. Originally derived from the thermodynamic theories, the concept of entropy was introduced in information theory. Entropy is a measure of the degree of disorder, uncertainty, or randomness of a probabilistic system, while information entropy can also measure the effective amount of information of the data.

The Entropy-weight method is applied in many fields of study. If there are m criterions and n objects which need to be evaluated, the entropy of the *i*th criterion is defined as *Hi*:

$$H_i = -k\sum_{j=1}^{n} f_{ij}\ln(f_{ij}) \quad (i = 1,2,\dots,m) \tag{4}$$

where $f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}$, and $k = \frac{1}{\ln(n)}$. And we assume that when $f_{ij} = 0$, $f_{ij}\ln(f_{ij}) = 0$. In essence, the larger the entropy *Hi*, the less information it is possible to provide. For instance, if most of the partners are judged as very close to the entrepreneurs, the assessment of closeness (r) would not be an efficient indicator for the tie strength, since it can not provide enough information or distinction to differentiate various strengths of tie. Therefore, the entropy weight of the *i*th criterion can be calculated by

$$w_i = (1 - H_i)/(m - \sum_{i=1}^{m} H_i) \tag{5}$$

Using formula 3-4 and 3-5, the entropy weights for the three indicators of tie strength can be calculated, as $w_u = 0.30, w_r = 0.38, w_c = 0.32$. And the formula for the "tie strength" is as follows:

$$d_j = w_u u_j^* + w_r r_j^* + w_c c_j^* \tag{6}$$

where for d_j, a higher value indicates a relatively tighter relation, thus deeper "depth" (min: 0; max: 1). Apparently, the spin-off has a deeper "depth" with the first partner, or a stronger tie.

A recent study by Asheim et al. (2007) summaries that the region is a key level at which innovative capacity is shaped and economic processes coordinated and governed, indicated by recent work on innovation systems. As firmly nested and highly relying on external knowledge network, open innovation benefits of USOs may be more readily achieved in regional clusters, since the effect of networks on innovation seems magnified by geographic proximity. Hence the relations are enhanced by the geographical proximity of partners, which is appropriate to deepen the "depth" of external knowledge from a specific knowledge content. Therefore the formula of external knowledge depth for a knowledge source is proposed as follows:

$$D_i = (1 + \alpha_i) \times \frac{\sum_{j=1}^{B_i} d_j}{B_i} \tag{7}$$

where α_i is the "locus enhancement factor" for knowledge content *i*, draw from the assessment of entrepreneurs (i.e., the added value of incubator for USOs assessed by their founders). The multiply relationship is to indicate the "magnification" effect of this factor

Openness diversity

$$Der_m = (1 + \frac{EI}{2}) \times Hs \tag{8}$$

where $Hs = 1 - \sum_{k=1}^{8}(\frac{a_k}{N})^2$

where a_k is the number of partners of a different social background, with $k = 1\ (big\ or\ normal\ business), 2\ (government), 3\ (university), 4\ (small\ business),$ $5\ (family\ or\ friends), 6\ (Venture\ Capatialists), 7\ (lead\ customers), 8\ (others)$.

N is the total number of partners a USO interacts with, and a higher value indicates a higher level of social background difference (min: 0; max: 1). For instance, a USO has five partners, two of whom are university professors, one comes from another small business, and the other two are lead customers. Thus, the social background diversity can be calculated as:

$$Hs = 1 - ((\frac{2}{5})^2 + (\frac{1}{5})^2 + (\frac{2}{5})^2) = 0.64$$

And $$EI = \frac{E_p - I_p}{E_p + I_p} \quad (9)$$

where E_p is the number of external (non-local) partners (>60 minutes car driving, regarding the "Randstad" area as a whole region) and I_p is the number of local partners ($E_p + I_p = N$). A high value indicates a relatively strong external orientation (min: -1; max: 1). Example, one of five partners of a USO is non-local partner, thus the value of spatial orientation is $EI = \frac{1-4}{1+4} = -0.6$.

Annex 2

In order to verify the reliability of the **factor analysis** results, three methods were used, namely, principle factor, principle-component factor and maximum-likelihood factor. The high consistency between the results implied that the factor analysis was highly reliable and robust.

Prospector strategy

Methods	Principle factor			Principle-component factor			Maximum-likelihood factor		
Variables	Number of items	Retained factors	Factor loading	Number of items	Retained factors	Factor loading	Number of items	Retained factors	Factor loading
Newness in innovation strategy	3	1	0.61	3	1	0.78	3	1	0.61
Patenting strategy			0.77			0.87			0.83
R&D expenditure			0.76			0.86			0.80

Annex 3

Summary of linear regression diagnostics: openness models (n=105)

Diagnostic	*Description*	*Capacity*		*Diversity*	
Model		1	2	1	2
Detecting unusual and influential data	Residuals, leverage, Cook's D and DFBETA, etc.	Checked	Checked	Checked	Checked
Test for normality of residuals	Inter-quartile range (iqr) test and Shapiro-Wilk test	iqr test:1 outlier Shapiro-Wilk test: z: -1.155 p-value: 0.88	iqr test: 1 outlier Shapiro-Wilk test: z: -0.257 p-value: 0.60	iqr test:1 outlier Shapiro-Wilk test: z: -1.838 p-value: 0.97	iqr test: 2 mild outliers Shapiro-Wilk test: z: 0.051 p: 0.48
Test for heteroscedasticity of residual	(1) white's test; (2) Breusch-Pagan test	(1) chi2: 18.52 p-value: 0.86 (2) chi2: 0.38 p-value: 0.54	(1) chi2: 35.78 p-value: 0.34 (2) chi2: 0.41 p-value: 0.52	(1) chi2: 32.20 p-value: 0.46 (2) chi2: 1.61 p-value: 0.20	(1) chi2: 36.52 p-value: 0.06 (2) chi2: 4.47 p-value: 0.03
Test for multicollinearity	Variance inflation factor	Mean VIF: 1.12	Mean VIF: 1.25	Mean VIF: 1.17	Mean VIF: 1.26
Test for model specification error	ovtest	F: 0.48 p-value: 0.70	F: 1.63 p-value: 0.19	F: 2.47 p-value: 0.07	F: 2.09 p-value: 0.11

Annex 4

The protection of newness variable was a candidate to be endogenous. The protection of newness may correspond to the strategy of openness. Naturally, to be more open could lead to more protective strategy toward new knowledge. Moreover, it may also be better expressed by other exogenous variables like knowledge base, age and ambition level. Therefore, the endogeneity of this variable was checked in each model, if present. Both Durbin and Wu-Hausman statistics were calculated for the endogeneity test. Overall, there were no indications for endogeneity.

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